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MEANINGFUL SIMILARITY AND INTERFERENCE IN LEARNING*

BY CHARLES E. OSGOOD

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INTRODUCTION

It is commonly agreed that learning one set of materials affects the subsequent learning of another set and that the subsequent learning in turn affects the recall of the original material. Agreement does not extend, however, to the conditions determining the direction and degree of effect. It may be facilitative (proactive or retroactive facilitation) or interfering (proactive or retroactive inhibition[1]). A specific instance concerns the role of similarity. Although there is complete agreement that the similarity between successively practiced materials is an important factor, there is considerable disagreement as to exactly how varying similarity affects the amounts of facilitation or interference obtained.

The major controversy has centered about retroaction, and the literature in the field presents a sharp contradiction. On the one hand the Skaggs-Robinson hypothesis predicts decreasing retroactive interference with increasing similarity (approaching identity), while on the other hand a series of studies by McGeoch and others (**21**) has led to the empirical generalization that 'the greater the similarity, the greater the retroactive interference.' Both statements have been substantiated by considerable experimental work.

The Skaggs-Robinson hypothesis, as it has been presented by Robinson (**26**), is illustrated by the curve in Fig. 1. The vertical

* This article is part of a dissertation presented to the faculty of the Department of Psychology of Yale University in partial fulfillment of the requirements for the Ph.D. degree.

[1] Interference is a better term here than inhibition. As it is used in these connections (*cf.* McGeoch), the term refers to an observed decrement in learning or recall and not to a process. The observed decrement may or may not be due to inhibition. Henceforth in this paper the term 'interference' will mean observed decrement and the term 'inhibition' will be reserved for the psychological process.

dimension represents efficiency of recall and the horizontal dimension, degrees of similarity. It should be noted carefully, however, that only two degrees of similarity are actually defined; point *A* indicates maximum similarity (identity) and point *C* indicates minimum similarity. Point *B* defines no degree of similarity, but rather the point of minimum efficiency of recall (i.e., the lowest point on the curve). Several studies, by Robinson (**26**), Harden (**12**), Kennelly (**16**), Cheng (**4**), B. Watson (**31**), and Dreis (**8**), have combined to give rough validation to this poorly defined hypothesis. All agreed in finding that, for relatively high degrees of similarity, the greater the similarity the less the retroactive interference.

The paradox arises when the above results are compared with those found in studies by McGeoch and McDonald (**19**), Johnson (**14**), and McGeoch and McGeoch (**20**). Using meaningful adjectives

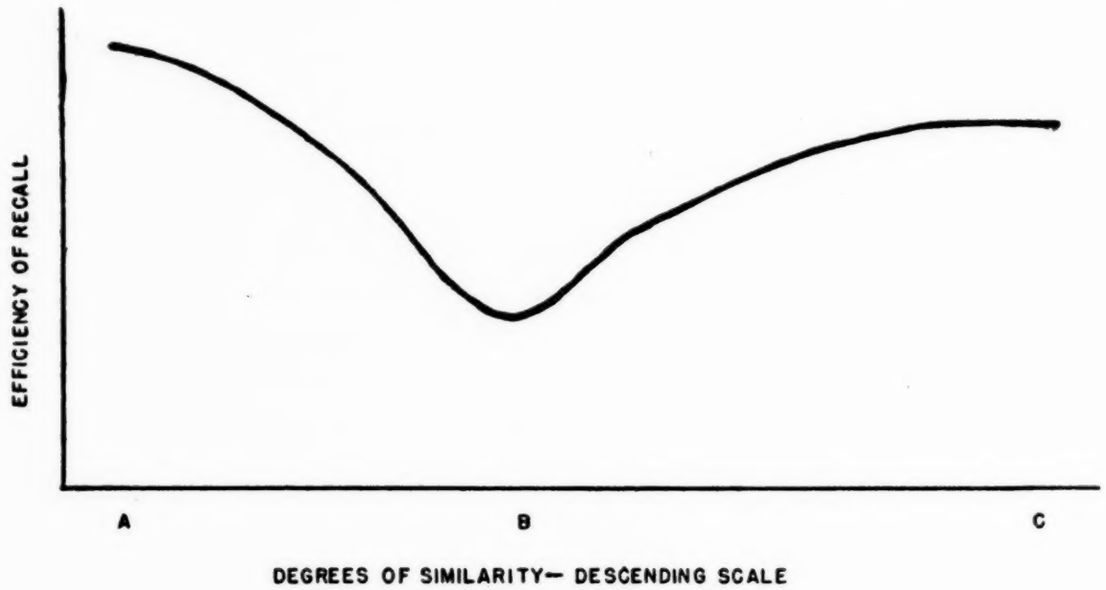

FIG. 1. The Skaggs-Robinson hypothesis

or nouns as original learning materials, these studies showed that as the judged similarity of the interpolated materials decreased through synonyms, antonyms, neutral words, nonsense syllables and three-place numbers, retroactive interference decreased. In part of the McGeoch and McDonald study (**19**), judges ranked words similar to the original lists into three degrees of synonymity, and again it was found that the less the judged similarity, the less the obtained retroactive interference. These studies were unanimous in finding retroactive interference to be an increasing function of similarity.

In *The psychology of human learning* (**21**) McGeoch attempted to resolve this paradox in two contradictory ways. In one place he distinguished 'degrees of identity' and 'similarity of meaning' as two different dimensions of similarity, each having a different function

in relation to interference in learning. Such a resolution suggests itself immediately: Robinson's studies employed number and letter combinations in which similarity was measured by the number of identical elements, while in the McGeoch group of studies, degrees of similarity were indicated by judgments about the meanings of English words. This solution may be questioned on several grounds, however. Several studies yielding the Skaggs-Robinson function (*cf.* Dries (**8**) with code-substitution and Watson (**31**) with card sorting) employed materials and procedures where 'degrees of identity' become far less definable than in the case of Robinson's work. Indeed, such a resolution presupposes an analysis of similarity in relation to some theory of identical elements. Moreover, as will be shown later, the results of the present experiment render such a resolution untenable, since meaningful materials are used but the results would fit 'degrees of identity' as the functioning dimension.

At a later point in the same chapter, McGeoch proposed an alternative resolution. In discussing the results of the McGeoch and McDonald study (**19**), he said, "there is no hint of the Skaggs-Robinson relation here or in many other experiments, not because the relation is invalid, but because the conditions are not set up to reveal it; instead, they measure the relation only over one section of it." The section referred to is presumably that between *B* and *C* (Fig. 1), since McGeoch found efficiency of recall to increase with decreasing similarity. This resolution also runs into difficulties: (1) since, as has been shown, point *B* defines no degree of similarity but merely the low point in the curve, given the multi-directional shape of the function, almost any conceivable obtained results could be fitted to one or another portion of the theoretical curve; (2) the resolution is completely incapable of proof or disproof, since, no matter how similar the original and interpolated materials, it can still be argued that their similarity does not fall within the *A—B* section of the curve; and (3) the results obtained in the present experiment, employing meaningful materials, fit the *A—B* portion of the Skaggs-Robinson function.

The major purpose of the present research was to achieve a more satisfactory resolution of this paradox by demonstrating that retroaction may be *either* an increasing or a decreasing function of similarity, depending on the nature of the learning paradigm employed. The traditional retroactive interference paradigm is *A—B; A—K; A—B.* This is the form in which it is usually stated, and it may be seen that the stimulus members are identical, the response members varying. In the experiments by McGeoch and McDonald (**19**), McGeoch and McGeoch (**20**), and Johnson (**14**), however, the actual paradigm was one in which *both* stimulus and response members

varied. To demonstrate conclusively that it is the nature of the paradigm employed and not the nature of the materials that is responsible for the paradoxical results, the present experiment uses meaningful materials, but also follows the traditional retroactive interference paradigm. Retroactive interference is found to decrease as similarity increases.

Methods

This experiment studied the differential interference effects produced in the successive learning of materials varying in terms of meaningful similarity. Sets of paired associates were learned by 60 *S*s, students in the writer's introductory psychology classes, by the anticipation method in which the stimuli were letter-pairs, such as *t.g.* and the responses were common adjectives. The traditional retroactive interference paradigm was followed (*A—B; A—K; A—B*), in which the experimental variable was the meaningful relationship between *B* and *K* adjectives. Three degrees of meaningful relationship were employed: similar (S), neutral (N) and opposed (O) words. The experiment was so designed that each *S* learned interpolated materials having five words in each of the three meaningful relations to the original materials and each word in the original learning functioned equally in all three meaningful relations to its interpolated words. Thus individual *S*s and individual words served as their own controls.

I. *Materials.*—Adjectives to be used in the experiment were selected to be within the functioning vocabulary of the average college sophomore and of roughly equal length and familiarity. The *E* selected words having synonym, similar, neutral, opposed, and direct opposite meaningful relations to a given set of adjectives, and this selection was then validated by a group of 20 judges. In the actual experiment only similar, neutral and opposed words were used, synonyms and direct opposites being omitted, since they involve considerable previous over-learning of the related pairs of words.

In selecting the meaningfully related words, *E* followed certain criteria. The synonym and direct opposite of a given word were from those given as such in dictionaries of synonyms and antonyms. Words selected as similar (S) to the original words are not synonyms by the above criterion, but do have the same feeling-tone and are to a large extent interchangeable descriptively, as for example *dejected-low*, *free-open*, *noisy-excited*, *weighty-serious*, and *tense-hard*. Words selected as opposed in meaning (O) to the original words are not antonyms according to the above criterion, but they do have opposed feeling-tone, as for example *dejected-high*, *free-closed*, *noisy-calm*, *weighty-humorous* and *tense-soft*. Neutral words were selected on the basis of having no recognizable (to *E*) similarity or opposition to the original words.

Twenty judges ranked the related words in terms of their similarity and opposition to the original words. Of the 15 items (original word and its meaningful relations) finally used in the experiment, five showed no cases of judges disagreeing with *E*'s selection, six items showed only one judge disagreeing, three items yielded disagreements by two judges, and on only one item did as many as three of the 20 judges disagree with *E*'s selection. This method of selecting the materials guarantees that words selected as similar (S) are more similar to the original words than the neutral (N) words and less similar than those selected as synonyms; it does not indicate degrees of similarity nor does it guarantee that neutral words are perfectly neutral.

Table I presents all the adjectives used in the experiment in terms of their meaningful relations. Half (30) of the *S*s learned one set of 15 words as original materials (O.L.$_1$), while the other half of the subjects learned as original material the direct opposites of these words (O.L.$_2$). Since identical sets of interpolated material were used in both cases, a further control over the selection of words is provided: each interpolated word having an S relation with a given word on O.L.$_1$ necessarily has an O relation with its opposite on O.L.$_2$; thus, identical words are made to function in both similar and opposed meaning relations. For example, the interpolated word *high* is similar in meaning to *elated* (the word having the same stimulus, c.m., on O.L.$_1$) while it is opposed in meaning to *dejected* (the word having the same stimulus on O.L.$_2$).

II. *Design.*—In Table I the materials are arranged in terms of their meaningful relations. The actual experiment was so designed that the interpolated materials learned by each *S* would include an equal number of words in each relation, S, N, and O. This minimizes the likelihood of *S*s' developing a 'set' for a given type of relation, such as similars or opposites. Such a 'set'

TABLE I

ADJECTIVES EMPLOYED IN THE EXPERIMENT IN TERMS OF THE MEANINGFUL RELATIONS BETWEEN ORIGINAL AND INTERPOLATED MATERIALS

Stim.	O.L.$_1$	Interpolated Learning (I.L.)			O.L.$_2$
		Meaningful Relations with O.L.$_1$			
		S	N	O	
		Meaningful Relations with O.L.$_2$			
		O	N	S	
c.m.	elated	high	left	low	dejected
f.s.	tense	hard	basic	soft	relaxed
g.l.	free	open	odd	closed	restricted
h.v.	dainty	clean	curious	dirty	coarse
j.y.	robust	solid	long	flimsy	puny
k.t.	neat	clear	numb	hazy	messy
d.m.	skillful	quick	sour	slow	awkward
p.j.	distinct	sharp	rancid	blunt	blurred
q.r.	slender	airy	daily	solid	stout
r.h.	noisy	excited	equal	calm	quiet
t.g.	drowsy	dead	necessary	alive	alert
v.k.	weighty	serious	common	humerous	spritely
w.p.	boorish	rough	near	smooth	gracious
x.n.	rounded	graceful	lucky	clumsy	angular
y.b.	pale	sickly	similar	healthy	brilliant

facilitates the learning of relations that are standardized in the culture, which is especially true in the case of opposites. Most studies in this field (*cf.* McGeoch and McDonald, 19) have presented materials in the form of lists in which all words have the same meaningful relationship to the original learning, thus not controlling this factor.

The rotational design used in this experiment may best be seen by referring to Table II.

TABLE II

EXPERIMENTAL DESIGN FOR INTERPOLATED LEARNING FOR ALL SUBJECTS HAVING THE SAME ORIGINAL LEARNING (O.L.$_1$ OR O.L.$_2$)

		Subgroups of Subjects on Interpolated Learning		
		I	II	III
Meaning Relation	S	(a) b c d e	f g h i j	k l m n o
	N	k l m n o	(a) b c d e	f g h i j
	O	f g h i j	k l m n o	(a) b c d e

This design applies to either the 30 *Ss* learning O.L.$_1$ or to the 30 learning O.L.$_2$. Each of these original learning groups was subdivided into three groups of 10 *Ss* each on the interpolated learning (sub-groups I, II, III), each of which learned a different set of materials. The letters in the design refer to specific items.

A concrete example will clarify the nature of this design. Let (*a*) represent the item having the stimulus *c.m.* All 30 *S*s in O.L.$_1$ learned the paired-associate *c.m.—elated* as one of the 15 pairs in the original learning. Following (*a*) through the design for interpolation it will be seen that subgroup I had the similar relation for this item, learning *c.m.—high;* subgroup II had the neutral relation, learning *c.m.—left;* and subgroup III had the opposed relation, learning *c.m.—low.* Each item was rotated through this matrix in similar fashion. Thus each original-learning word had interpolated (with a different group of *S*s) one word in each of the three meaningful relations, while each *S* learned as interpolated material five words in each of the three meaningful relations.

III. *Apparatus.*—The usual method of presenting paired-associates has been to have them in serial lists. Although this is the most feasible method when a memory drum is used, it admits serial interactions in learning, which in many experiments are not desirable. The apparatus designed for this experiment made possible continuous randomization of the items. Another difficulty with the memory drum is that different items are learned to different degrees, some overlearned and others underlearned, since trials are necessarily given in terms of whole lists. The apparatus used here made it possible to drop items from the set as they were learned to any desired degree.

The *S* sits facing a dull-black plywood screen in which, at approximately eye-level, is a window wherein the materials are presented, illuminated by a small lamp attached to the rear of the screen. This window is divided into left and right halves by a thin bar, the stimuli appearing on the left and the responses on the right. In the presentation of a given paired-associate, the stimulus-member appears first for four seconds, the right-hand half of the window being covered by a shutter through this period; then, for a two-sec. period, the response-member is revealed as well; there is then a final two-sec. period with the entire window covered by the shutter, during which time the item is changed.

The stimulus letters and response adjectives were printed in large block type on thick cards, one card for each paired-associate. Each card has a hole punched near the top so that it may be hung in the thread of a continuous screw. This screw is rotated by a constant speed Telechron motor, and the cards are thus caused to move slowly out along the screw, the front card only being visible to the *S* through the window. When the front card drops from the end of the screw, the next card in order is revealed. By a gear system the rotary speed of the screw is cut down to one revolution every eight sec., one card dropping with each full revolution of the screw.

As noted earlier, the window is covered by a rotary shutter which is also painted dull-black and is attached to the rear of the screen. This shutter is made of thin tin and is cut out in such a fashion that all, half or none of the window may be covered at a given time. The shutter is turned by a weight attached to the end of a thin but strong fishline which runs over a pulley, placed near the ceiling to give maximum excursion to the weight before rewinding. Brass pins are set at equal distances about the hub of the rotary shutter. A ratchet, contacting one of these pins, holds the shutter in a given position; sending current through an electromagnetic coil shoots the ratchet out and then in again, thus permitting the shutter to move to the next position. By adjusting the weight on the pulley, the shutter may be made to move quickly and smoothly; increasing the friction on the shutter-shaft prevents the shutter from bouncing.

Synchronization of the movements of the cards out along the screw with the turning of this rotary shutter is secured by having the contacts which activate the electromagnetic ratchet device governed by the revolutions of the Telechron motor. A bakelite collar on the screw shaft is set with four equally spaced copper contact points. As these points pass a stationary copper brush, the electromagnetic coil is activated, this occurring once every two sec. In this way the dropping of the cards from the end of the screw is synchronized with the full covering of the window by the shutter. This device also provides constant timing for the presentation of the materials.

Equal learning of the different paired-associates was accomplished by eliminating any card from further presentation after the *S* correctly anticipated the response word. If, on a given trial, an item has not been learned to the criterion, it drops from the end of the screw and, striking a tray, slides onto the middle level of the apparatus box. This tray is set at an angle of about 45° and the wooden block on which it is secured is held against the rear of the screen by two light springs. A strong cord connects this tray, over a system of pulleys, to a foot-pedal which may be operated by *E* from his position behind *S*. When an item which has just been mastered by an

S drops from the end of the screw, *E* presses this pedal, thus moving the tray back and allowing that card to drop through to the lower level of the apparatus-box. Mastered and unmastered items are thus segregated.

IV. *Procedure.*—Following the retroactive interference paradigm, the general procedure was as follows: each *S* first learned one set (O.L.) of 15 paired-associates to a criterion of one correct repetition; then a second set (I.L.) of 15 paired-associates was learned to a criterion of two correct repetitions; finally, the *S* was given three trials on the original materials. The paired-associates were learned by the anticipation method in which the *S*, presented with the stimulus, must anticipate the correct word by making the correct response out loud before the word actually appears. The following instructions were read to each *S:*

> This experiment is designed to test *how rapidly* you can learn 15 paired items, when the stimuli (ON THIS SIDE, pointing to the stimulus side of the window) are two letters such as 'l.z.' and the responses (ON THE OTHER SIDE, pointing to the response side of the window) are meaningful words.
>
> Each letter-pair will be shown for 4 seconds; the meaningful word that you are to learn will follow for 2 seconds. Following the appearance of each stimulus, you must learn to say the correct meaningful word *out loud before* that word is revealed. Always try to say the correct word *as quickly as you can* since I am measuring the speed of your responses as well as the correctness.
>
> You do not have to wait until you are absolutely sure of the correct word since good guesses are not penalized. On the other hand, do *not* guess at random since this will just get you mixed up.
>
> The order of the items will be varied for every trial. Individual items will be dropped out of the list as you learn them.
>
> In between each trial, while I am replacing the cards back here, will you put all of your thought and energy into trying to solve this puzzle (POINT TO IT). It is a very difficult puzzle and most people don't finish it in the time they have, but do as much of it as you can.
>
> Now, on this first time through the series, say each letter-pair out loud when you first see it. Then, when the response word appears, say it out loud with as much expressiveness as you can—get the meaning of the word.

Certain significant details in the procedure must be clarified. The *timing of the stimulus and response members* in such a way that the stimulus is exposed for four sec. and the response word for two sec. was designed to permit a latency measurement as a more sensitive indicator of habit strength than the mere presence or absence of the correct response. The activation of the electromagnetic coil produced a sharp, distinctly audible click every two sec., and on this basis *E* was able to indicate roughly the latency of *S*'s responses after the stimulus first appeared. If the correct response was made between the first click (appearance of the stimulus letter-pair) and the second, this response was scored '1'; if the response was made between the second click and the third (appearance of the response word), this response was scored '2'; if the response occurred after the third click or failed to occur, it was scored '3.' All incorrect reactions (intrusions) were recorded, such cases also being counted '3' in the calculations. These latency scores have been called interpretatively *interference values*, and are the basis on which the results are reported. The larger the value, the greater, theoretically, the interference (or the poorer the recall).

In both the original and the interpolated learning, after 10 of the 15 items had been mastered to the criterion (and dropped from the set), *one review trial* was given with all 15 items to equalize as much as possible the degree of learning of the items mastered early with those more recently mastered and those still not quite learned. The dropping out technique employed here to equalize learning of individual items has been used by Sand (27).

The *method of randomizing the item cards*—alternating front and back positions in the new pack as the cards were picked up after each trial—does not guarantee a *chance* distribution of serial positions. It does however guarantee that no set order could be learned by the *S*s, which was the purpose of the randomization. *Implicit practice between trials* was minimized by having the *S*s work hard at a complicated jig-saw puzzle. The constant exhortation by *E* to get as much done as they could, plus the fact that usually much of the puzzle was completed, makes it seem unlikely that there was much uncontrolled rehearsal of the memory materials.

Predicted and Obtained Results

I. *Theoretical predictions.*

This study deals with verbal behavior, and the experimental variable is meaning. It is assumed that spoken and written words and other symbols have meaning to the extent that they, as stimuli, evoke a distinctive pattern of reactions on the part of the organism, this pattern or reactions 'representing' that to which the word or symbol refers. This distinctive pattern of behavior will be termed a 'meaning reaction.' Thus the word *tense* is assumed to have meaning to the extent that it, as a stimulus, produces certain distinctive responsive activity, possibly minimal excitation of those voluntary muscles which, if fully activated, would result in hand-clenching or straightening of the back. It is important to note that these are *mediating* reactions. They produce internal stimulation (proprioceptive, chemical, etc.), and this stimulation may serve as the cue for various overt responses, among which is the vocalization of the appropriate word.

Following the behavioral conception of meaning briefly outlined above, these dynamic factors in learning are presumed to be operating in the present experiment:

(*a*) that with every reinforced repetition of the association between a stimulus and a meaning reaction, an increment of excitatory habit tendency for that stimulus to evoke that reaction is generated.
(*b*) that simultaneous with every increment of excitatory tendency, an equal inhibitory tendency is generated for that stimulus *not* to evoke the directly opposite meaning reaction.
(*c*) that successive excitatory and inhibitory increments in habit tendency summate algebraically.
(*d*) that both excitatory and inhibitory habit tendencies generalize, such generalization occurring both among meaning reactions and among the stimuli produced by these reactions.

Since meaning reactions are considered to be mediating reactions, it is assumed that the greater the tendency for a given stimulus to evoke a given meaning reaction, the greater will be the tendency to make the appropriate overt vocal response, the latter habits being greatly overlearned.

With the exception of factor (*b*), the above principles are taken from Hull's behavioral theory (**13**). The principle that learning to make a response involves simultaneously learning not to make the antagonistic reaction originated in previous work on which the writer collaborated (**15, 29**), these investigations concerning the function of meaningful opposites in synesthesia and social thinking.

(1) *Proactive predictions.*—In the course of the original learning (O.L.) of the paired-associate *c.m.—elated*, for example, generalized excitatory tendency will also be generated for that stimulus (*c.m.*) to evoke a *similar* meaning-reaction (*high*), the amount of this generalized tendency being greater than zero and less than that associating the stimulus with the original reaction. Theoretically, no habit tendency will be generated for that stimulus (*c.m.*) to evoke a *neutral* response (*left*), since such a response is assumed to be beyond the generalization gradient. On the other hand, since inhibitory habit tendency has been generated for the stimulus (*c.m.*) not to evoke the directly opposite reaction (*dejected*) and since inhibitory tendencies also generalize, it follows that in the course of the original learning inhibitory tendency will also be generated for that stimulus not to evoke the *opposed* reaction (*low*), this response being similar to the directly opposite response. The amount of this generalized inhibitory tendency will be greater than zero and less than that associated with the directly opposite reaction.

The theoretical situation at the conclusion of the original learning may be diagrammed as in Fig. 2. The white portion indicates

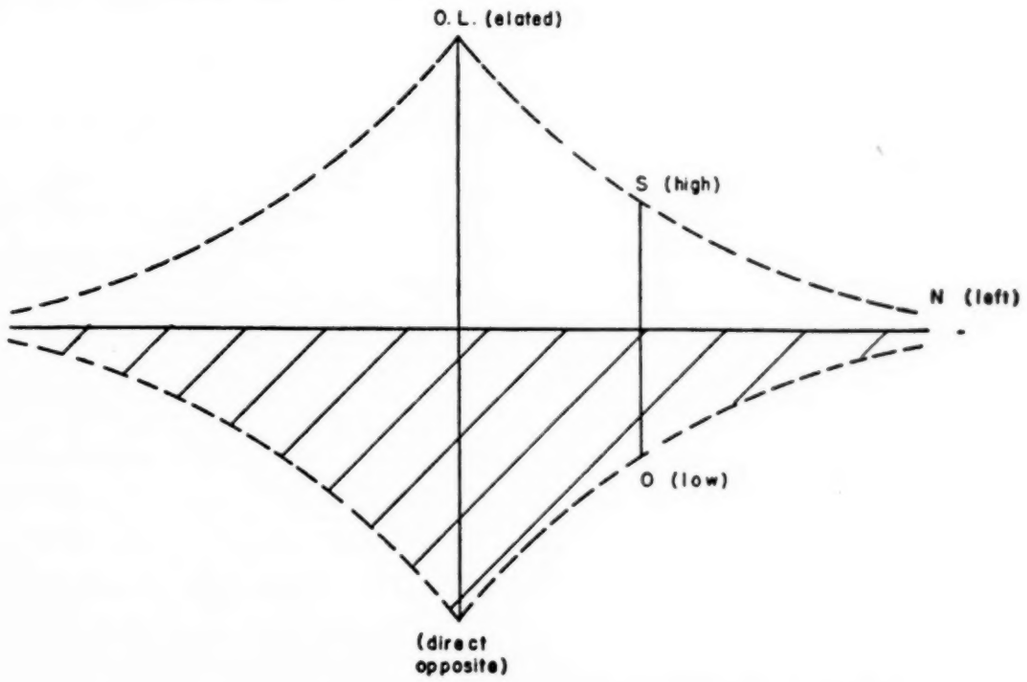

FIG. 2. Theoretical situation at the conclusion of the original learning

excitatory tendency and the shaded portion inhibitory tendency. The generalization gradients are drawn in dashed lines to indicate that discrete reactions rather than a continuous dimension are being dealt with. The theoretical situation diagrammed here for the paired-associate *c.m.—elated* is assumed to be common to all the items used.

Since the interpolated learning (test for proactive interference) followed immediately the conclusion of the original learning, interference effects for the different experimental conditions may be predicted from the habit strengths existing at that point. The S word is already partly associated with the given stimulus through generalization, the N word has received no generalized practice, while the O word has an inhibitory association with the stimulus. *It may therefore be predicted that S words will show the least proactive interference, N words more, and O words the most interference.*

(2) *Retroactive predictions.*—Although the factors functioning in the interpolated learning are presumably the same as in the original learning, the *effect* produced on the original association necessarily varies with the meaningful relation between the original and interpolated words. Fig. 3 provides graphic illustration for the state-

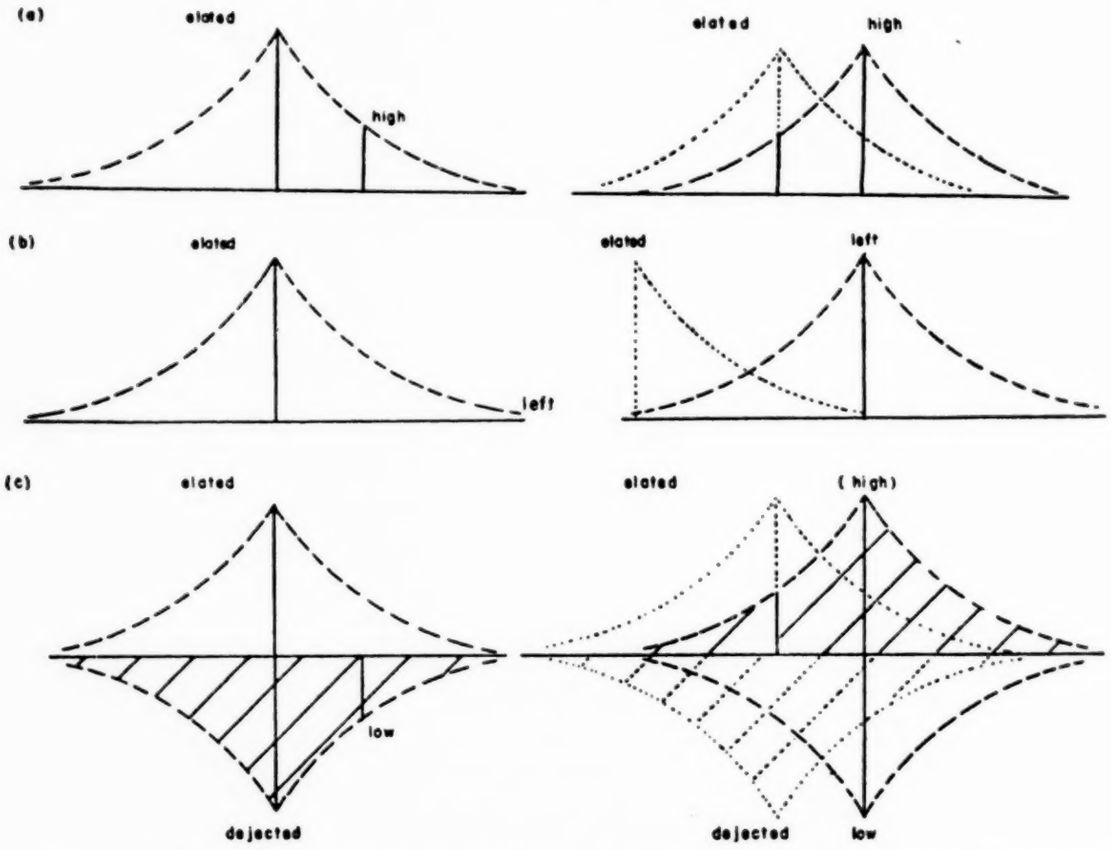

FIG. 3. Theoretical situations at conclusion of original learning (left) and effects of interpolated learning (right) for similar (*a*), neutral (*b*) and opposed (*c*) interpolated materials.

ments to follow. In this figure, the diagrams at the left indicate the theoretical situation at the conclusion of the original learning, and those on the right indicate the effect of the interpolated learning—for similar (*a*), neutral (*b*), and opposed (*c*) interpolations. Since all interpolated words were learned to the same criterion, it is assumed that habit strengths associating the stimuli with the interpolated responses are equal at the conclusion of this learning.

Where a *similar* (S) word is interpolated, with every increment in the tendency for the stimulus (*c.m.*) to evoke the interpolated word (*high*), a generalized increment is also generated for that stimulus to evoke the original reaction (*elated*). Since generalized and original excitatory tendencies summate, it follows that in the course of the interpolated learning of a similar word there is also increment in the original association.

Where a *neutral* (N) word is interpolated there is theoretically no effect on the original association. By the same token that there is no generalization between neutral words during original learning, there is no generalization during interpolation. Thus, the interpolated learning of *left* has no effect on the original habit tendency associating *c.m.* with *elated.*

Analysis of the effect of interpolating an *opposed* (O) word is more complex since both generalization and conditioned inhibition are simultaneously involved. With every increment in the tendency for the stimulus (*c.m.*) to evoke the interpolated O response (*low*), there is a simultaneous increment of inhibitory tendency for that stimulus not to evoke the response directly opposite to the one being learned. In this case the directly opposite reaction would presumably be *high.* Since the word originally associated with the stimulus (*c.m.*), *elated*, is similar to *high*, whatever conditioned inhibition is associated with *high* theoretically generalizes toward the original reaction, *elated.* It may be seen, then, that whereas excitatory tendency has been developed during the original learning, inhibitory tendency has been generated during the interpolated learning. Since excitatory and inhibitory tendencies are assumed to summate algebraically, it follows that the interpolated learning of an opposed word results in a *decrement* in the strength of the original association.

To summarize the retroactive predictions, the effect of interpolating a similar word is to increase the original habit tendency, the effect of interpolating a neutral word is to leave the original habit tendency unchanged, and the effect of interpolating an opposed word is to decrease the original habit tendency. To the extent, then, that ease of recall of the original responses is a function of the habit strengths associating them with the appropriate stimuli, *it is predicted that retroactive interference will be least for S words, greater for N words, and greatest for O words.*

The fact that for both proactive and retroactive situations increments in habit strength theoretically result from the successive learning of similar words brings up a terminological problem. Should we not speak of (and predict) facilitation rather than interference? Since this experiment was designed to measure *relative* interference effects for different degrees of similarity, no rest condition (itself a

questionable control) was provided, and hence it cannot be said definitely whether we are dealing with interference or facilitation. In any case, facilitating, neutral and interfering effects form a continuum, and it is along this continuum that predictions are made.

(3) *Intrusion predictions.*—Since all incorrect responses (intrusions) were recorded, it is possible to check predicted frequencies of intrusions under the different experimental conditions against obtained frequencies. As the effect of interpolation is being studied, predictions concern *related inter-list intrusions.* In this case, both the correct word and the intruded word have been associated with the *same* stimulus and hence the determining factors are those governing the relative strength of the tendency for one reaction to occur as compared with the other in a response-competition situation.[2] Four such factors may be designated:

(1) the initial strength of the tendency for the correct reaction to occur.
(2) the initial strength of the tendency for the intruding reaction to occur.
(3) changes in the strength of the tendency for the correct reaction to occur during the course of learning that reaction.
(4) changes in the strength of the tendency for the intruding reaction to occur during the course of learning the correct reaction.

Factors 2 and 3 are theoretically nondifferential under the conditions of this experiment. Since all responses (S, N, and O) in both original and interpolated learning are mastered to the same criterion, their initial tendencies to occur as intrusions in the subsequent test (factor 2) are presumably equal. Since all responses are practiced equally (until they are mastered and dropped from the list), changes in the tendencies for these correct reactions to occur during the course of their learning (factor 3) are presumably equal.

Factor 1 does function differentially. Through generalization of excitatory tendency in the case of S words and generalization of inhibitory tendency in the case of O words, the initial strength of the tendency for the correct reaction to occur is greatest for the S condition and least for the O condition, for both proactive and retroactive situations. Other things being equal, the less the tendency for the correct reaction to occur, the greater will be the tendency for the intruding reaction to occur. Therefore, if this were the only factor producing related intrusions, they should be most frequent under the O condition and least under the S condition.

[2] In this analysis the 'correct' reaction in the proactive situation is the interpolated word, while the 'correct' reaction in the retroactive situation is the original word.

Turning to factor 4, it would seem that, where learning the correct reaction also functions to increase the association of the stimulus with the intruding reaction, there should be a greater tendency for intrusion of this related word than where learning the correct reaction functions to decrease the tendency for the intruding reaction. With every strengthening of the correct S reaction in both proactive and retroactive situations, there is generalized strengthening of the related (intruding) reaction as well. On the other hand, with every strengthening of the correct O word, there is generalized inhibition developed toward the related (intruding) word. It follows that, during the course of either the interpolated learning or the retroactive test, the tendency for S intrusions relatively increases while the tendency for O intrusions relatively decreases. Therefore, if this were the only factor producing related intrusions, they should occur most frequently in the S condition and least frequently in the O condition.

If the opposition between these two operative factors were completely continuous, no differential predictions could be made, but this can be shown not to be the case. Factor 1 (initial strength of the tendency for the correct reaction to occur) favors intrusions under the O condition and *is maximal at the beginning* of both the proactive and retroactive tests. Factor 4 (changes in the strength of the tendency for the intruding reaction to occur during the course of the learning of the correct reaction) favors intrusions under the S condition and *becomes increasingly differential with every succeeding trial.* It should be expected, therefore, that the ratio of S intrusions to O intrusions should increase with the number of trials in a given learning situation. In the proactive situation of the present experiment an average of seven trials was given (including the review trial on which intrusions were recorded); in the retroactive test only three trials were given. On this basis, it may be predicted that *the ratio of S related inter-list intrusions to O related inter-list intrusions will be greater in the proactive situation than in the retroactive situation.*

II. *Obtained results.*

Following the design of the experiment, each *S* learns as interpolated material five words in each of the three meaningful relations, S, N, and O. This being the case, each *S* acts as his own control, and the interference values for one meaningful relation may be compared directly with those for another meaningful relation. Intersubject variables (such as learning speed, susceptibility to interference effects, etc.) are thus controlled.

(1) *Proactive results.*—Table III presents the proactive interference results on the basis of the total of 60 *S*s. The upper portion of this table gives the means and sigmas for the distributions of three

TABLE III

MEANS AND SIGMAS OF THE DISTRIBUTIONS OF INTERFERENCE VALUES FOR THE TOTAL 60 SUBJECTS ON THE INTERPOLATED LEARNING

		Meaningful Relation		
		S	N	O
(*a*) 1st trial	M	2.49	2.67	2.67
	σ	.434	.342	.330
(*b*) 1st and 2nd trials comb.	M	2.39	2.55	2.53
	σ	.411	.341	.348
(*c*) No. trials to crit.	M	4.46	4.72	4.77
	σ	1.65	1.62	1.93

SIGNIFICANCE OF DIFFERENCE IN MEAN INTERFERENCE VALUES FOR THE TOTAL 60 SUBJECTS ON THE INTERPOLATED LEARNING IN TERMS OF *t*-VALUES

	S/O		S/N		N/O	
	t	level	*t*	level	*t*	level
(*a*) 1st trial	3.23	1%	3.70	1%	.00	—
(*b*) 1st and 2nd trials comb.	2.79	1%	3.21	1%	.37	—
(*c*) No. trials to crit.	2.14	5%	1.71	10%	.31	—

measures: (*a*) *1st trial*, in which each case was the average interference value for the five words in a given meaningful relation for a single *S* on the first trial of the interpolated learning; (*b*) *1st and 2nd trials combined*, in which each case was the average interference value for the five words in a given meaningful relation for a single *S* on the first and second trials combined; (*c*) *number of trials to reach criterion*, in which each case was the average number of trials required for a single *S* to reach the criterion of two correct repetitions for the five words in a given meaningful relation. The lower portion of this table gives the significance of these mean differences in terms of the probability of such differences being obtained by chance, as determined by the *t*-technique.[3]

Inspection of the table of *t*-values shows that the differences between S and either N or O conditions are clearly significant and in the

[3] The formula employed here was

$$t = \frac{\frac{\Sigma d}{n}}{\sqrt{\frac{\frac{\Sigma d^2}{n} - \left(\frac{\Sigma d}{n}\right)^2}{n-1}}}$$

in which d equals the difference in average interference value between the five words of one meaningful relation and the five words of another meaningful relation for a single *S*, and n equals the number of such differences (60). With 59 degrees of freedom a *t*-value of 2.66 is significant at the one percent level and a *t*-value of 2.00 is significant at the five percent level.

predicted direction. There are, however, no significant differences between N and O conditions. The predictions made for proactive interference are partially verified. The learning of words that are similar to previously learned words is accompanied by significantly less proactive interference than the learning of words that are either neutral or opposed in meaning to the original words. The expectation that opposed words should produce more proactive interference than neutral words is not fulfilled.

A clear-cut demonstration of the differential effect of similar and opposed meanings on verbal learning provided by this design is the comparison of proactive interference values for *the same interpolated words* when a similar word or a word of opposed meaning has been learned in the original materials. It will be recalled that 30 *S*s learned O.L.$_1$ and the other 30 *S*s learned O.L.$_2$, the words in one original list being the direct opposites of those in the other. Since identical sets of interpolated material were learned by both groups, an interpolated word having an S relation to a given word on O.L.$_1$ necessarily has an O relation to the opposite on O.L.$_2$. In the total design there are 30 such comparisons where the interpolated word is constant but its meaningful relation to the original learning is varied.

Table IV presents the mean interference values for this compari-

TABLE IV

MEAN INTERFERENCE VALUES FOR SAME WORDS FUNCTIONING IN S AND O RELATIONS, AND SIGNIFICANCES OF DIFFERENCES

	Means		*t*-value	Level
	S	O		
1st trial	2.49	2.68	3.59	1%
1st and 2nd trials	2.39	2.51	2.41	5%
Trials to crit.	4.47	4.76	2.64	5%

son, along with the significance of differences in terms of *t*-values. The S relation is found to produce significantly less proactive interference by all three measures employed. Since subgroups of *S*s may be assumed to be equivalent, the *S*s having been assigned at random, clear demonstration is offered that the same word is more difficult to learn if an *S* has previously learned a word of opposed meaning to the same stimulus than if he has learned a word of similar meaning. Since the learning of the identical word is being measured, the variable responsible for these consistent differences is presumably the similarity or opposition in the meaningful relation.

(2) *Retroactive results.*—To measure retroactive interference effects, three trials on the original materials were given immediately

following the mastery of the interpolated learning. The first trial is a pure recall trial while the others necessarily involve some relearning. Table V presents the retroactive interference results on the basis of

TABLE V

MEANS AND SIGMAS OF THE DISTRIBUTIONS OF INTERFERENCE VALUES FOR THE TOTAL 60 SUBJECTS ON RECALL OF THE ORIGINAL LEARNING

		Meaningful Relations		
		S	N	O
(*a*) 1st trial	M	2.36	2.43	2.43
	σ	.486	.393	.434
(*b*) 2nd trial	M	1.97	2.12	2.14
	σ	.533	.469	.529
(*c*) 3rd trial	M	1.78	1.94	2.00
	σ	.539	.480	.500
(*d*) Av. all trials	M	2.04	2.16	2.19
	σ	.465	.424	.428

SIGNIFICANCE OF DIFFERENCES IN MEAN INTERFERENCE VALUES FOR THE TOTAL 60 SUBJECTS ON RECALL OF THE ORIGINAL LEARNING IN TERMS OF *t*-VALUES

	S/O		S/N		N/O	
	t	level	*t*	level	*t*	level
(*a*) 1st trial	.99	—	1.06	—	.00	—
(*b*) 2nd trial	2.07	5%	2.21	5%	.29	—
(*c*) 3rd trial	2.89	1%	2.08	5%	.91	—
(*d*) Av. all trials	2.42	2%	1.94	10%	.61	—

the total 60 subjects. The upper portion of this table gives the means and sigmas for the distributions of four measures: (*a*) *1st RI trial*, (*b*) *2nd RI trial*, (*c*) *3rd RI trial*, and (*d*) *average of all RI trials*, in each of which a case was the average interference value[4] for the five words having a given meaningful relation to the interpolated materials for a given *S*. The lower portion of this table gives the significance of these mean differences in terms of the probabilities of such differences being obtained by chance, as determined by the *t*-technique.

With the exception of the first RI trial, the obtained means follow the predicted trend, the S condition yielding the smallest interference values and the O condition the largest. In terms of the significance of these mean differences, although there are no significant differences

[4] Where a given word was not mastered (given correctly once) in the original learning or the review trial, its failure to be 'recalled' on the retroactive test seems more likely due to failure of original impression than to the effects of the interpolated learning, which is the variable with which the present study is concerned. Therefore, all such cases were omitted in computing retroactive results.

on the first trial, differences between S and O conditions are significant for both the second and third trials and for the average of all trials combined, while differences between S and N conditions are significant on the second trial and nearly so on the other measures. Again there are no significant differences between the N and O conditions.

With the learning paradigm used here, then, the interpolation of similar words between the learning and recall of the original materials is found to produce significantly less retroactive interference than the interpolation of words of either neutral or opposed meanings. Interpolation of opposed words does not produce significantly more interference than interpolation of neutral words, although where differences are obtained they are in the predicted direction and tend to increase in magnitude with the number of recall trials.

Proactive and retroactive results have also been calculated on the basis of the total of 30 words as the sample and in terms of the proportions of Ss and words affirming and denying the predictions made. These results duplicated the findings reported above in every respect and are not therefore presented.

(3) *Intrusion results.*—Intrusions have been categorized as follows: *related inter-list* (intrusion of the word from the previously learned list having the same stimulus-member as the correct word), *unrelated inter-list* (intrusion of a word from the previously learned list not having the same stimulus-member as the correct word), *extra-list* (intrusion of a word not included in the lists practiced), *similar* or *opposite* (intrusion of an extra-list word which is judged (by *E*) to be closely similar or opposite to the correct word), and *intra-list* (intrusion of a word from within the list being practiced). In Table VI total frequencies of intrusions falling into the above categories are given. The numbers of intrusions were probably somewhat lowered by the instructions—not to guess at random.

TABLE VI

FREQUENCIES OF ALL TYPES OF INTRUSIONS FOR DIFFERENT EXPERIMENTAL CONDITIONS

	Proactive			Retroactive		
	S	N	O	S	N	O
Related inter-list	21	13	5	40	36	33
Unrelated inter-list	12	9	10	21	18	32
Extra-list (miscl.)	9	11	16	5	5	4
Similar extra-list	8	3	1	5	4	3
Opposite extra-list	0	0	5	1	0	1
Intra-list	155	143	156	57	89	70
Total all intrusions	205	179	193	129	152	143

Intrusion of words *similar* to the correct responses is most frequent in the S condition and least frequent in the O condition. This trend would be expected, since amount of generalization is a function of habit strength and the interpolation of similar words theoretically augments the correct habits involved while mutual decrement results in the case of interpolating opposed words. It may also be noted that six out of seven cases of intrusion of words *opposite* in meaning to the correct responses occur in the O condition, the only condition theoretically adequate to produce such intrusions. However, the small number of cases in these categories does not warrant statistical analysis.

The prediction that the ratio of S *related inter-list* intrusions to O related inter-list intrusions should be greater for the proactive than the retroactive situation is clearly borne out. Inspection of Table VI shows that whereas this ratio is 21/5 in the proactive situation, in the retroactive situation it is only 40/33. Statistical evaluation of this difference has been made in terms of the numbers of *S*s for whom such intrusions occur. This analysis does not make use of all the data, since the same *S* sometimes has more than one case of a related intrusion occurring in the same experimental condition. Table VII

TABLE VII

NUMBERS AND PERCENTAGES OF SUBJECTS GIVING RELATED INTER-LIST INTRUSIONS IN DIFFERENT EXPERIMENTAL CONDITIONS

	Proactive		Retroactive	
	N	%	N	%
S	16	.27	20	.33
N	9	.15	23	.38
O	5	.08	24	.40

SIGNIFICANCE OF DIFFERENCES IN TERMS OF CRITICAL RATIOS

	Proactive		Retroactive	
	C.R.	Ch./100	C.R.	Ch./100
S/O	2.00	2	1.11	13
S/N	1.13	13	.81	21
N/O	1.71	4	.32	37

gives the numbers and percentages of *S*s giving related inter-list intrusions under the different experimental conditions, S, N, and O, for both proactive and retroactive situations. The lower portion of this table gives the significance of these differences in terms of critical ratios and the probability of differences of such magnitude occurring by chance.

The difference in percentage between the S and O conditions for the proactive test (.27/.08) would be expected to occur by chance only twice in 100 times. This is true despite the fact that all the unused relevant data are cases of duplicate S intrusions. On the other hand, the difference in the retroactive situation (.33/.40) is of much smaller magnitude, and in fact reverses the trend obtained when all the data are used (raw frequencies of intrusions as compared with numbers of subjects giving such intrusions). The implications of this finding will be considered in the discussion.

Discussion

Meaningful similarity and interference in learning.—The most widely accepted generalization in this field has been that 'the greater the similarity in meaning, the greater the interference,' in the learning of successively practiced materials. This statement has been substantiated in carefully executed experiments by McGeoch and McDonald (**19**), McGeoch and McGeoch (**20**), and Johnson (**14**). It is to be found in most textbooks in psychology and has been used as the basis for practical recommendations for efficient techniques in studying, learning languages, training military personnel, and other such important fields.

The present investigation seriously questions the unrestricted applicability of this generalization by presenting results which directly contradict it. Using meaningful adjectives as materials in the traditional retroactive interference paradigm, this experiment fulfills the conditions under which this generalization is supposed to function. In every comparison made, for both proactive and retroactive situations, similar meaningful relations produced *less* interference in learning than neutral meaningful relations. It may be concluded that this empirical law does not have general validity.

Resolution of the paradox.—The contradiction between results fitting the Skaggs-Robinson hypothesis and those found by McGeoch and others may be resolved by demonstrating that retroaction may be either an increasing or a decreasing function of similarity, depending on the stimulus and response relations among the materials successively practiced. The present investigation follows the paradigm *A—B; A—K; A—B;* stimulus members are constant, and as similarity between *B* and *K* adjectives increases, interference decreases.

In the McGeoch-McDonald experiment (**19**), which may be taken as the classic study yielding results opposed to the above, *serial lists* were learned by the anticipation method. In this form of learning, each word serves as the stimulus for the next in the list as a response, which in turn serves as the stimulus for the next word, and so forth. In the interpolated lists, each word bears its meaningful relation

(synonym, similar, neutral, etc.) to the word in the original list having the same serial position. The learning paradigm in this case is *A—B; A′—B′; A—B*, where *both* the stimulus and the response members vary.

McGeoch and McDonald found that as the judged similarity between the related words on the two lists increased, retroactive interference also increased. This result would be predicted from the hypotheses followed here, given the nature of the paradigm used. Due to the similarity between the stimulus-members, *A* and *A′*, in the course of the original learning of *A—B*, *A′* also develops a generalized tendency to evoke *B*. During the interpolated learning of *A′—B′*, the original stimulus word *A* also develops a generalized tendency to evoke *B′* as a response. In this paradigm, the generalized tendencies are toward *wrong* responses, *A—B′*, and *A′—B*. The *greater the similarity* between the stimulus-members, the greater will be the generalization between them, and hence the greater will be the tendency to make wrong responses, resulting in greater measured retroaction.

Restatement of laws governing interference in learning as a function of similarity.—This resolution of the paradox suggests the possibility of a general reformulation of the laws of interference in relation to similarity.

(1) *Under conditions of learning in which either the stimulus members or the response members are identical in the materials successively practiced, the greater the similarity between the varied members, the less the proactive or retroactive interference.*

(2) *Under conditions of learning in which both the stimulus and response members are simultaneously varied in the materials successively practiced, the greater the similarity between the stimulus members* (or between response members?) *the greater the proactive or retroactive interference.*

The literature in this field has been inspected to determine to what extent these statements are substantiated experimentally. To give as wide a generality to these statements as possible, this survey of the experimental literature has included both proactive (transfer) effects and retroactive effects and both, what are usually distinguished as, 'meaningful' and 'nonmeaningful' materials. This review is necessarily limited to those studies where the stimulus-response relationships are analyzable, and the further limitation of space prevents detailed description of the experiments indicated.

The first statement above—concerning those conditions in which either the stimulus or response members are held constant—is verified for *proactive* effects by Yum (**32**) and the writer for meaningful materials and by Yum (**32**), Bruce (**3**), Watson (**31**), and Hamilton

(11) for nonmeaningful materials. The *retroactive* expectations arising from this first statement are borne out in the present experiment for meaningful materials, and it is apparently the only study fitting the necessary conditions of identity for either stimulus or response members that employs meaningful materials. The retroactive predictions are, however, amply substantiated with nonmeaningful materials by Dreis (8), Watson (31) and Hamilton (11).

The second statement—concerning those conditions in which both stimulus and response members are simultaneously varied—is borne out for *proactive* effects with meaningful materials in studies by McGeoch and McGeoch (20) and Johnson (14), although the obtained differences in both cases were not very great. McGeoch and McDonald (19) do not report any data bearing on the relative difficulties of learning the interpolated materials. Experiments by Gibson (10) and Melton and Von Lackum (24) fulfill the necessary conditions for the functioning of the second law where nonmeaningful materials are employed, and the expected results are obtained. *Retroactive* effects are amply verified by McGeoch and McDonald (19), McGeoach and McGeoch (20) and Johnson (14) for meaningful materials, while Gibson (10) presents substantiating results with nonmeaningful materials.

It would contribute greatly to the simplicity and generality of the second law if similarity among response members functioned in the same way as similarity among stimulus members. This possibility is indicated in the parenthesis in the second statement, but unfortunately no studies have been found in the literature in which the stimuli are different and neutral while the responses vary in their similarity. This represents a gap in our empirical information which needs filling.

To the extent that this coverage and analysis of the literature has been adequate, the two laws stated above are substantiated by the experimental findings. No results have been encountered which contradict them. Such a reformulation serves three purposes. (1) It resolves the paradox presented by the Skaggs-Robinson studies and the results found in the McGeoch group of experiments. (2) It removes the necessity for distinguishing either between meaningful and nonmeaningful materials or between 'similarity' and 'degrees of identity' as dimensions having different functions in relation to interference. (3) It makes possible further integration of the findings within and between the fields of transfer and retroaction.

Relation of this research to theories concerning the causes of retroactive interference.—A series of studies by McGeoch and his associates (21) has built up evidence for a transfer or competition-of-response theory which identifies retroactive interference (RI) with the process

of reproductive inhibition. According to this theory, a response is inhibited when another response takes the place of it, the recall of *B* in response to *A* being inhibited by the recall of *K* instead.

Gibson (**9**) has offered a generalization hypothesis which attributes the measured retroaction to confusion (indiscriminability) among the responses as a result of generalization among the stimuli in the original and interpolated materials. This is a refinement of the competition theory which leads to more definitive statements as to the stimulus conditions determining the amount of response competition obtained.

The competition-of-response theory explains total RI in terms of one factor—the competition of responses at the point of recall. Melton and Irwin (**23**) have recently questioned such a single-factor theory by demonstrating that the amount of RI attributable to competition of responses is not sufficient to account for the total RI obtained. The amount of RI attributable to competition is assumed by both Melton (**23**) and McGeoch (**21**) to be *indexed* by the frequencies of overt intrusions. This is only an index, since much of the competition is assumed to be implicit.

That one or more additional factors are necessary to explain retroactive inhibition was indicated in the Melton and Irwin study by the fact that, as the number of trials on the interpolated learning was increased, the frequency of overt intrusions during the retroactive test decreased while total measured RI never-the-less increased. The function of the other factor, called 'Factor X,' was determined by subtracting that part of the total RI attributable to competition from the total obtained RI. It was found to be a continuously increasing function of the number of interpolated trials, and it was tentatively identified as an 'unlearning' factor. That is, the unlearning of the original responses is assumed to occur when they are made (intrude) during the interpolated learning—being 'wrong' responses, they are unrewarded and hence unlearned.

If 'Factor X' is thus identified with unlearning during interpolation, then, in exactly the same sense that frequency of overt intrusions during the retroactive test is considered an index for the competition factor, *the frequency of overt intrusions of the original responses during the interpolated learning is an index of the amount of this unlearning factor.* In other words, before a response can be unlearned through non-reward, it must occur—i.e., it must be made as an overt or implicit intrusion. The data presented by Melton and Irwin (**23**) do not fit this expectation; the frequency of overt intrusions of original responses during the interpolated learning does not increase regularly with number of interpolated trials.

The intrusion results of the present experiment complicate this

theoretical situation still more. It will be recalled that the interpolation of opposed words produced significantly greater RI than the interpolation of similar words. If this difference in total RI were to be explained in terms of a *competition-of-response factor*, then more frequent intrusion of the interpolated words in the opposed condition than the similar would be expected during the retroactive test. But no significant differences in frequencies of related inter-list intrusions were found for the retroactive test; in fact, total frequencies favored the similar condition. If the obtained difference in total RI were to be explained in terms of an *unlearning factor*, then more frequent intrusion of the original words would be expected in the opposed condition than the similar condition during the interpolated learning. This expectation is clearly refuted, since related intrusions are found to occur with significantly higher frequency for the similar condition during the interpolated learning.

To summarize: neither a competition-of-response factor nor an unlearning factor is adequate to account for the clearly significant difference in total RI between the similar and opposed meaningful interpolations of this experiment. It would seem that, if the indexes employed to indicate the magnitudes of these factors are accepted, and they seem theoretically justifiable, then yet another factor must be postulated as producing retroactive interference.

A possible factor would be one based on the hypothesis, followed in this paper, that learning one response necessarily involves the simultaneous inhibition of opposed responses. This 'reciprocal inhibition' would fit the function which Melton and Irwin have indicated as characteristic of 'Factor X.' That is, its magnitude would increase at a negatively accelerated rate with the number of interpolated trials. In common with 'Factor X,' such 'reciprocal inhibition' would result in decrement in the habit strengths of the original associations, but its operation does not necessitate the occurrence of either overt or implicit intrusions. Although such a hypothesis was instrumental in interpreting the intrusion findings in the present experiment, its functioning would also be expected to produce greater total RI for opposed interpolations than neutral interpolations, and this expectation was only suggested in the data.

Summary

Comparison of studies supporting the Skaggs-Robinson hypothesis with those by McGeoch and others using meaningful materials presents a paradox: the former find retroaction to be a decreasing function of similarity (high degrees), while the latter find it to be an increasing function. The McGeoch studies all follow a learning paradigm in which both stimulus and response members are simultane-

ously varied. The present experiment follows the traditional retroactive inhibition paradigm—*A—B; A—K; A—B*—in which the stimulus members are constant. The experimental variable is the meaningful relationship between *B* and *K* adjectives.

The obtained results show that both proactive and retroactive interference are significantly less for similar adjectives than for either neutral adjectives or adjectives opposed in meaning. Opposed meanings produce more retroactive interference than neutral meanings, but the obtained differences are not significant.

The following conclusions are drawn: (1) the widely accepted statement—'the greater the meaningful similarity, the greater the interference'—does not have general validity. (2) Interference in learning may be either an increasing or a decreasing function of similarity, depending on the stimulus-response relationships in the materials successively practiced. (3) Intrusion results of this experiment are analyzed in relation to current theories as to the cause of retroactive inhibition, and neither McGeoch's 'competition-of-responses' factor nor Melton's 'Factor X' incorporates them.

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SUCCESS AND FAILURE IN SERIAL LEARNING. II. ISOLATION AND THE THORNDIKE EFFECT

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Thorndike has stated in his law of effect that a pleasurable after-effect strengthens a stimulus-response connection. In serial learning, he has observed, a pleasurable after-effect strengthens not only the connection that it follows, but also those punished connections which neighbor upon it (**14**). The closer the punished connection, the more it is strengthened. Muenzinger and Dove (**9**) have termed this latter result, after its discoverer, the 'Thorndike effect.'

Köhler and Von Restorff (**7**) have shown that isolation of an item in a series of items causes it to be remembered more than non-isolated items. Now, calling a response 'right' amid a large number of verdicts to other responses of 'wrong' would have the effect of isolating the right response or making it stand out. Reasoning from Köhler's and Von Restorff's findings, this isolation should contribute to its reproduction. The isolation of *stimulus items* in a series should likewise influence repetition of successive responses made to them.

The experiments reported herein were designed to determine whether the results Thorndike attributes to the influence of a pleasurable after-effect may not be traceable at least partially to the influence of isolation. The 'isolation' of an experience is used herein to mean the *stand-out* character of an experience which *sets it apart* from other experiences.

Experiment III

This experiment was designed to determine the result of isolating a few punished responses among many 'crowded' or non-isolated rewarded responses. This contrasts with the customary technique of isolating a few rewarded responses among many crowded punished ones. In this way, the effect of reduction of isolation of rewarded responses may be measured.

* This is the second of two articles based on a dissertation presented in partial fulfillment of the requirements for the Ph.D. degree, Duke University, 1941. The investigation was directed by Dr. D. K. Adams.

Procedure

A list of 59 nonsense syllables and one different, and thus isolated, nonsense item, 'lsjbcz quenbtm,' was constructed. These were presented to individual *Ss* at two-sec. intervals per item for a total of 11 times without interruption. A rotary tachistoscope was used for the presentation. By a prearranged plan, responses to six of the nonsense syllables in the list were called 'wrong' on each presentation. All other responses were called 'right.' The responses called wrong were so spaced in the series that four separate right responses would occur on either side of each wrong response. Thus, a possible gradient effect might easily be measured. Responses to the polysyllabic item, 'lsjbcz quenbtm' (56th in the series), were called 'right.' It was introduced to determine the effect of producing isolation of a right response among other right responses which were crowded.

Twenty *Ss* participated in the experiment. All were students in Hanover College. The following instructions were read to them:

> "I shall show you in the slot on the apparatus before you a series of words to each of which are assigned numbers from 1 to 10. You are to respond to each of these words immediately by calling out the first number from 1 to 10 inclusive which occurs to you. I you call out the right numbers I shall say 'right,' and if you call out any other numbers I shall say 'wrong.' Will you try to repeat the numbers called right for the different words each time that they come around and avoid the numbers called wrong."

At the conclusion of the experiment, the *Ss* were asked two questions: "Did you consistently try to give the same numbers for words where they had been called right?", and "Did you consistently try to avoid numbers for words where they had been called wrong?" These questions were asked to determine the practice of the *Ss* in the face of so many numbers called right. All answered the questions in the affirmative.

Results

The results were calculated by the method described in the first of these two articles (**18**). Reports of five *Ss* were discarded because of a mechanical way of calling number responses. One *S*, for instance gave the number '1' for all syllables having the letter 'z' and the number '5' for all syllables having the letter 'v.' Results from the remaining 15 *Ss* are shown in Table IV.

TABLE IV

CROWDED RIGHT RESPONSES ABOUT AN ISOLATED WRONG RESPONSE

	Right Responses Preceding by Steps:				Wrong Resp.	Right Responses Following by Steps:			
	4	3	2	1		1	2	3	4
Possible repetitions	849	849	849	849	849	849	849	849	849
Actual repetitions.	151	144	142	134	140	135	130	127	136
Percent repeated..	17.8	17.0	16.7	15.8	16.5	15.9	15.3	15.0	16.0

Percent of right responses repeated on all eight steps—16.2

Table IV shows a slightly higher percentage of repetition for all wrong responses (16.5) than for all right responses (16.2). The percentage of repetition of crowded *right* responses in this experiment is comparable to the percentage of repetition of crowded *wrong* responses obtained in several other experiments. Percentages of repetition of *isolated* right responses in other experiments substanti-

ally or greatly exceed those obtained with the *crowded* right responses in this experiment. This is markedly true in the experiment following, No. IV.

The list of syllables used in this experiment was practically identical with a list used by the author in a similar experiment employing 15 Ss, in which a few responses were called right and most were called wrong (**17**). This latter experiment can thus serve to some extent as a control. In it, the percentage of repetition of wrong responses to the syllables four steps before and after a right response was 15.8. This is 0.4 lower than the 16.2 percentage obtained in the present experiment. But, while responses in the present experiment were called *right*, responses in that other experiment were called *wrong*. Thus, there was a repetition advantage of only 0.4 percent when responses were called right instead of wrong.

Interestingly enough, there is a suggestion of the Thorndike effect on the first three steps following a wrong response. It is reversed on the four steps preceding a wrong response.

Table V shows a special calculation of repetitions for the isolated

TABLE V

RESPONSES AROUND THE ISOLATED ITEM 'lsjbcz quenbtm'

	Right Responses Preceding by Steps:				lsjbcz quenbtm	Right Responses Following by Steps:			
	4	3	2	1		1	2	3	4
Possible repetitions	—	—	148	148	148	148	148	148	148
Actual repetitions	—	—	14	23	85	49	41	33	27
Percent repeated	—	—	9.5	15.5	57.4	33.1	27.7	22.3	18.2

Percent repeated on all six steps—21.1

item 'lsjbcz quenbtm,' the two syllables preceding, and the four syllables following it. Responses to all of these items were called right.

Table V shows a large difference in repetition percentages favoring the isolated item, in spite of the fact that responses to all items were called right. A definite Thorndike effect appears in this table, though the responses about the isolated item were all pronounced 'right' and not 'wrong.'

From these results, it appears that calling many responses right, and thus crowding them, results in lowered rates of reproduction. Isolation of a right response has the opposite effect. Isolation of wrong responses does not show this result, however. The Thorndike effect appears herein with rewarded responses around an isolated rewarded response.

Experiment IV

In contrast to the aim of Experiment III, this experiment was designed to determine the effect of progressive degrees of isolation of right responses upon their repetition and upon the repetition of neighboring wrong responses.

Procedure

A list of stimulus objects composed of 60 items was used. These were presented by means of a rotary tachistoscope. There was one nonsense syllable printed on the tachistoscopic disc in red capital letters, whose responses were always called right. It was 39th in the list and the most isolated of the items. There were three words of eight letters, each printed in black capital letters. They came at the 18th, 53rd, and 59th positions in the list. Responses to the first two of them were always called right, and they were the second most isolated of the items. Responses to the third, 'WITHDRAW,' were automatically called wrong, thus providing a condition of a wrong response isolated among other wrong responses. There were, finally, 56 words of eight letters, each printed in black, lower case letters. Responses to five of these were always called right, thus providing a third degree of isolation of right responses. All other responses were called wrong. The right responses were so spaced that each one would have three separate wrong responses both preceding and following it.

After the original list had been presented to half of the *S*s, it was changed slightly to control any possible influence attaching to specific words. In the second form of the list, a different nonsense syllable was used and 'right' words traded place with 'wrong' [1] words following them by three steps.

The list was presented to each *S* for a total of 11 times without interruption. A new item was presented every two sec. The prearranged plan for calling responses 'right' or 'wrong' was departed from in a few instances where it appeared to the *E* that the *S* might possibly suspect the arbitrary manner of calling his responses right or wrong.

Twenty *S*s took part in the experiment. All were students in Hanover College. The following instructions were read to them:

> "I shall show you in the slot on the apparatus before you a series of words to each of which is assigned a number from 1 to 10. You are to respond to each of these words immediately by calling out the first number from 1 to 10 inclusive which occurs to you. If you call out the right number I shall say 'right.' If you call out any other number I shall say 'wrong.'"

Results

A comparison of Tables VI, VII, and VIII shows a clear-cut

TABLE VI

Wrong Responses about a 'Right' Nonsense Syllable Having the Greatest Degree of Isolation

	Wrong Responses Preceding by Steps:			Right Resp.	Wrong Responses Following by Steps:		
	3	2	1		1	2	3
Possible repetitions	190	190	190	195	195	195	195
Actual repetitions..	31	22	27	176	61	38	38
Percent repeated...	16.3	11.6	14.2	90.3	31.3	19.5	19.5
Percent repeated on the three steps...		14.0				23.4	

[1] 'Right' and 'wrong' refer to words the responses to which were called 'right' or 'wrong' by a prearranged pattern.

TABLE VII

WRONG RESPONSES ABOUT TWO 'RIGHT' CAPITALIZED WORDS HAVING THE SECOND FROM THE GREATEST DEGREE OF ISOLATION

	Wrong Responses Preceding by Steps:			Right Resp.	Wrong Responses Following by Steps:		
	3	2	1		1	2	3
Possible repetitions	288	288	288	289	288	288	288
Actual repetitions..	38	41	43	142	65	51	36
Percent repeated...	13.2	14.2	14.9	49.1	22.6	17.7	12.5
Percent repeated on the three steps...		14.1				17.6	

TABLE VIII

WRONG RESPONSES ABOUT FIVE 'RIGHT' LOWER-CASE WORDS HAVING THE THIRD FROM THE GREATEST DEGREE OF ISOLATION

	Wrong Responses Preceding by Steps:			Right Resp.	Wrong Responses Following by Steps:		
	3	2	1		1	2	3
Possible repetitions	840	840	840	842	833	833	833
Actual repetitions..	111	106	113	146	140	128	106
Percent repeated...	13.2	12.6	13.5	17.3	16.8	15.4	12.7
Percent repeated on the three steps...		13.1				15.0	

positive relation between degree of isolation of a right item and percentage of repetition of responses to it. With the three progressive degrees of isolation, we find the repetition percentages to be 17.3, 49.1, and 90.3. The Thorndike effect *following* a right response is similarly affected. The greater the degree of isolation of the right response, the greater the percentages of repetition of wrong responses and the steeper the gradient. The Thorndike effect *preceding* a right response is less clear-cut and is not greatly affected by the degree of isolation of a right response.

A special calculation was made for the isolated word 'WITHDRAW,' which was printed in black capitals, and for the four lower-case words around it. Responses to all of these words were called wrong.

Table IX shows an unusually large degree of response repetition to the 'wrong' isolated word 'WITHDRAW.' This may have been due to the *S*s confusion of this word with the other two capitalized words whose responses were always called right. A definite Thorndike effect will be noted. In Experiment III, the Thorndike effect appeared on *right* responses surrounding an isolated *right* response. In this experiment, a Thorndike effect appears on *wrong* responses

TABLE IX

WRONG RESPONSES ABOUT THE ESPECIALLY ISOLATED 'WRONG' WORD, WITHDRAW

	Wrong Responses Preceding by Steps:		WITHDRAW	Wrong Responses Following by Steps:	
	2	1		1	2
Possible repetitions.....	200	200	200	200	179
Actual repetitions.....	21	35	59	42	21
Percent repeated.....	10.5	17.5	29.5	21.0	11.7

Percent repeated on all four steps—15.3

surrounding an isolated *wrong* response. Thus, the effect is seen to appear under a variety of conditions.

EXPERIMENT V

Several investigators have found that a bell, an electric shock, or a light flash coincident with an *S*'s choice of response in a multiple-choice situation tends to cause repetition of the same choice on future occasions (**3, 4, 6, 10, 11, 12, 15, 16**). Other investigators have obtained contradictory results or have disagreed with the interpretations offered (**1, 2, 5, 8**). The main criticism by the latter of positive results obtained by the former is that a bell, a light flash, or a shock may be interpreted by the *S* as an indication that his choice is correct. If so, the enhanced repetition might be referred to the pleasant after-effect.

This experiment was designed to determine whether isolation of a response produced by the ringing of a bell would cause greater repetition of it and whether a Thorndike effect would appear around the isolated response. By a policy of misleading *S*s, a situation was created whereby *S*s responded with numbers of successive presentations of a list of 60 words without attempting either to *repeat* the same numbers for a given word or to *avoid* them. Some of the words were isolated from the rest by the ringing of a bell immediately after they had been presented. Thus the factor of isolation was introduced without complicating the situation at the same time by the desires of the *S* to repeat or avoid responses, or by associated experiences of success or failure.

Procedure

A list of 60 stimulus words was used, of which 59 were four-letter words. The remaining word, 'California,' 57th in the list, was isolated from the others by reason of its length. A push bell was rung immediately after the reading of the 5th, 14th, 32nd, 41st, and 50th words. The words were presented at intervals of approximately two sec. for a total of nine times. By actual measurement, the average interval of presentation for the words was 2.11 sec.

The experiment was conducted during a session of the author's general psychology class, 36 members of which participated. At the beginning of the experiment, the *S*s were given score sheets with nine columns of 60 blank spaces each and verbally instructed as follows:

"This is an experiment in the estimation of time. I shall read to you successively for a number of times a list of 60 words. You are to put down a number between 1 and 10 in each space on the sheet before you. Numbers must be put down in the blanks appropriate to each word—the first blank for the first word, the blank below it for the second word, and so on. Make it a point to mix your numbers up thoroughly rather than to put them down in a regular pattern. At certain intervals in the reading of the list I shall ring a bell. At the bottom of each column, I shall ask you to put down your estimate of the time consumed in going through the list of words. I hope by this test to determine something about the influence of these particular activities on the estimation of time. Will those of you with wrist watches please remove them now and place them in a pocket or somewhere else out of sight."

At the end of each reading of the list, the *Ss* were advised: "Will you now enter your estimate of the time consumed from the moment the first word was called to the moment the last word was called. Give it in seconds." They were then asked to fold under the column of numbers just entered so that they would not be visible. Before the beginning of the second list the *Ss* were reminded as follows: "Please remember to mix your numbers up thoroughly rather than to put them down in a regular pattern."

At the conclusion of the experiment the *Ss* were asked to write down their answers to the following questions:

"1. What is your estimate of the total time consumed by the experiment, from the first word called to the last word called?

2. What significance did you attach to the ringing of the bell, if any?

3. Did you try to give the same numbers for particular words on successive readings? For instance, did you give a certain number for the word 'mail' and then try to repeat it when the word 'mail' was called out on later readings of the list?

4. Did you try to avoid giving the same numbers for particular words on successive readings?

5. If you tried either to repeat or avoid repeating numbers for particular words on successive readings of the list, was that true for the words on presentation of which the bell was rung? If so, explain."

Twenty-two of the 36 *Ss* met the desired conditions by reporting in answer to the questions that they tried neither to repeat nor to avoid repeating number responses to particular words. Of this number, those who attached any particular meaning to the bell suggested in the main that it was meant to mark intervals of time. A few found it disturbing. No one of these 22 *Ss* reported recognition of its true 'isolating' function.

Results

TABLE X

RESPONSES AROUND A WORD WITH WHICH A BELL WAS RUNG

	Responses Preceding Bell by Steps:				Bell	Responses Following Bell by Steps:			
	4	3	2	1		1	2	3	4
Possible repetitions	1055	1055	1055	1055	1055	1055	1055	1055	1055
Actual repetitions	151	115	117	130	114	134	105	128	127
Percent repeated	14.3	10.9	11.1	12.3	10.8	12.7	10.0	12.1	12.0

Percent repeated on all eight steps—11.9

The amount of repetition of responses to words on which the bell was rung is low, 10.8. This figure is lower by 1.1 than the percentage of repetition of responses on the four steps preceding and the four steps following the responses on which the bell was rung. There is no indication here that isolation of a response, *per se*, serves to enhance repetition of it. In fact, the figures point in the opposite direction.

The Thorndike gradient appears to a slight extent about the words on which the bell was rung. It may be noted on the first three steps preceding and the first two steps following the bell response.

The percentage of repetition of response to the isolated word 'California' was very low, being only 8. This is 4.3 lower than the percentage of repetition of responses on the three steps preceding and following 'California,' which was 12.3. Isolation in this case was certainly not associated with enhanced repetition, but just the opposite.

Discussion

We may now consider the findings of these experiments with respect to Thorndike's conclusions that a pleasurable after-effect strengthens (1) the connection which it follows and (2) also those punished connections neighboring upon it.

Let us examine the first of these conclusions at this point. In Experiment III, the usual situation of few rewarded responses and many punished responses in a series was reversed to provide many rewarded responses and few punished. This made for the crowding of rewarded responses and the isolation of punished responses. The results show a marked decline in the percentage of repetition of right responses as contrasted with other experiments in which few responses were rewarded and many punished. Indeed, the percentage of repetition of *crowded right* responses (16.2) in this experiment was slightly less than the like percentage for the *isolated wrong* responses (16.5). In the absence of isolation, a pleasurable after-effect appears to have had little or no 'strengthening' effect upon the connection which it followed.

By contrast, in Experiment IV three progressive degrees of isolation of right responses were provided. The results show that the percentage of repetition of right responses increases with the degree of isolation. The percentage of repetition of right responses to the greatly isolated item in this experiment (90.3) was over five and one-half times as great as the percentage of repetition of right responses to the crowded items in Experiment III (16.2).

From Experiments III and IV it appears that isolation is an important contributing factor in determining rates of repetition of responses. However, in Experiment V, where isolation of a response was produced by the ringing of a bell and neither verbal reward nor punishment of responses was involved, very low percentages of repetition were obtained. The percentage of repetition of isolated responses (10.8) was less than that for non-isolated responses (11.9). In the absence of reward and punishment of responses and of motivation to repeat or avoid repeating them, isolation did not favor repeti-

tion. Hence, in the situation studied, it does not appear that isolation of a response, *per se*, promotes repetition of it. A complex of factors is required.

Let us now consider the bearing of these experiments upon Thorndike's second conclusion listed above, namely, that a pleasurable after-effect strengthens punished connections adjacent to the rewarded connection. This is his explanation for the Thorndike effect, of course.

Experiment III, in which crowded right responses are grouped around isolated wrong ones, shows a slight decreasing gradient on the three steps following a wrong response, but an increasing gradient on the four steps preceding. The law of effect could certainly not be invoked to explain the slight gradient appearing after a wrong response, for the verdict of 'wrong' could hardly be supposed to create a pleasurable after-effect.

Experiment IV showed a definite tendency for the slope of the Thorndike gradient following a right response to increase with increasing isolation of the stimulus to the right response. This was less clearly shown on the steps preceding a right response.

In Experiment II, reported in an earlier article (**18**), the Thorndike effect was seen to appear on wrong responses surrounding a key right response, even though the stimulus words for the wrong responses were shifted from one reading of the list to the next. Items on steps one and four exchanged positions and a like exchange occurred between items on steps two and three. 'Strengthening' of the neighboring responses would presumably be balanced by this technique, and the Thorndike effect should not be expected to appear. Responses were checked for repetition by their own step positions relative to the key response, and not by the positions of their stimulus words from the key response. In practice, the checking procedure was precisely the same as in the other experiments reported here in which the positions of the stimulus words remained constant. Results of this check showed a clear-cut Thorndike effect appearing on the three steps preceding and the three steps following the key response. The important consideration appears to have been the proximity of the pleasurable after-effect to the *response* rather than to the *stimulus-response connection.*

From the above results, it is seen that the decreasing gradient effect or Thorndike effect may appear under a variety of conditions. First, it may appear with wrong responses neighboring upon a right response. This is the condition explored by Thorndike and others. Second, it may appear with right responses surrounding an isolated right response. Third, it may appear with wrong responses neighboring upon an isolated wrong response. Fourth, it may appear in terms of *response* position rather than in terms of *connection* position.

In view of this variety of conditions under which the Thorndike effect may appear, we may demand a fuller explanation for the phenomenon than the law of effect, as advanced by Thorndike. His explanation refers only to the first condition for the appearance of the gradient, and does not account for the gradient effect occurring under the other conditions.

It seems to this author that a more workable theory to explain the enhancement of repetition of rewarded responses and also the Thorndike effect would involve the factor of isolation. Köhler and Von Restorff (**7**) have shown the influence of isolation in enhancing reproduction and the present results in general tend to support their findings. Thorndike (**13**) has recognized the influence of isolation to a certain extent in his principle of 'identifiability' in learning. However, he has apparently not recognized the role of the verdict of 'right' amid a large number of verdicts of 'wrong' in emphasizing or isolating a given response and in thus contributing to its repetition. Instead, he has used the law of effect to account for enhanced repetition. Tolman, Hall, and Bretnall (**16**) have pointed to the isolating influence of certain after-effects and have substituted three laws of learning to take the place of Thorndike's law of effect. These substitute laws are the law of motivation, the law of emphasis, and the law of disruption. Their laws of emphasis and of motivation lend themselves quite readily to an explanation of many of the results obtained in these experiments. The Thorndike effect, however, is not explained by them.

A working theory to account for the enhanced repetition of isolated responses and also for the Thorndike effect is herewith advanced. In the process of learning, the ability to perceive that which is to be learned is fundamental. When items to be learned stand out or are isolated from others, they may be identified more easily and remembered more readily than when they are crowded, embedded, or lost in the mass. Items of experience may become isolated in different ways. They may become isolated because of factors in the nature of the stimulating situation and because of factors in the response of the individual to the stimulating situation. An item of experience may stand out because its stimulus is unique or different from other stimuli about it. It may also stand out because it is connected or associated with some interest, emotion, feeling, or other isolated experience within the individual. Ordinarily, both inner and outer factors condition the development of isolation of an experience.

An example of external factors operating to produce isolation is provided by a single red apple in a basket of oranges, as contrasted with the same red apple in a basket filled with other red apples.

Under ordinary circumstances, the apple would excite more notice when among the oranges and one's response to it would be more isolated as a result. In these experiments, a nonsense syllable in red capital letters tends to stand out when it appears among many eight-letter words in small black letters. Recognition of the uniqueness of the red nonsense syllable results in a more isolated response to it than would occur if uniqueness were not present.

An example of internal factors operating to produce isolation of an experience is afforded by the exaggerated response of an apprehensive ghost-story reader to the creaking of timbers in his lonely house. Under ordinary circumstances, noises from heat contractions of the timbers would be paid scant notice. But when he is fearful, such sounds can have sinister interpretations and may assume a highly isolated character in his experience. In these experiments, feelings of pleasure or of disappointment coupled with the desire to repeat responses called right tended to produce isolation of responses to certain words, syllables, or objects.

This reasoning may be carried one step further. Once a response becomes isolated, it may operate to produce isolation of those responses close by it. Other factors being equal, we may hypothesize that the closer the neighboring response to the isolated response, the more it tends to become isolated by reason of that association.

The theory of isolation provides a much simpler explanation for the enhancement of repetition of a rewarded response than the somewhat mysterious law of effect. For instance, in commenting upon the action of a satisfying after-effect, Thorndike writes: "Beneath all deliberate choice, prior to all conscious selection, is the fundamental fact in nature that a satisfier strengthens tendencies which are 'at hand,' as it were, when the satisfier happens. From it issues a strengthening force, which they absorb" (**14**, p. 49).

Employing the theory of isolation, we might rather say that a satisfier *isolates* tendencies which are at hand when it happens. At least this may be so if the satisfier occurs infrequently, is unique, or outstanding. Knowledge of success may result in increased motivation to remember. Isolation and enhanced motivation favor learning. Thus we have an explanation for the enhanced repetition. The results of Experiment IV indicate that the enhancement of repetition is roughly proportional to the degree of isolation of the response. With such an interpretation, it becomes unnecessary to speak in terms of indefinite 'strengthening forces' or to postulate that a "satisfier acts upon (a punished connection) unconsciously and directly, much as sunlight acts upon plants . . . or the earth upon the moon" (**14**, p. 48).

The theory of isolation provides a clue to certain experimental

results which recently have puzzled Thorndike and his associates in research. They have noted that a punished response in a series tends to be repeated more often than responses that are neither punished nor rewarded. Inasmuch as the unpleasant after-effect would tend to isolate punished responses, it is suggested that the enhancement in repetition percentages might be traced partially to the isolation produced. The critic may say to this that isolation of a wrong response should enable an *S* to remember it better and thus avoid it later. Under some circumstances, this would no doubt be the case. But in an experimental situation involving large numbers of responses coming in quick succession, it is suggested that *S*s are more interested in remembering the responses they get right than those they get wrong. When only one number out of 10 is correct for a given item, an *S* will try to remember it; but when a number given is wrong, there are still eight other possibilities for a wrong response. As the old proverb goes, "A bird in the hand is worth two in the bush." One can remember only so much, so it is better to concentrate on retaining those responses which are right; for to get responses right is the main object of the series learning situations. Conversely, it is less wise to scatter one's energies trying to remember to avoid certain responses, especially since the chances of giving an incorrect response again are far in excess of those for giving a correct one.

The theory of isolation not only provides an explanation for enhanced repetition of rewarded or otherwise isolated responses, but also gives us an explanation for the Thorndike effect. It is suggested that responses neighboring upon a key response which has become isolated *tend to become isolated themselves* because of their association with the key response. Those responses one step away would tend to be most isolated, those two steps away next most isolated, etc. In general, the degree of isolation would tend to decrease with decreasing proximity to the key isolated response. Decreasing degrees of isolation would result in decreasing ratios of repetition, thus giving rise to the declining gradient or Thorndike effect. Should other isolating experiences come into the picture, the declining gradient would tend to be upset, of course. This occurs in these experiments with the special isolation of certain wrong responses surrounding a right response. In such a case, a gradient tended to appear around the especially isolated wrong response.

The theory of isolation will account for the Thorndike effect appearing under the variety of conditions mentioned previously, whereas Thorndike's explanation in terms of the law of effect applies to only one of them—the condition of wrong responses surrounding a right response.

In consideration of the experimental results presented, it may be concluded that the declining gradient, or Thorndike effect, is not an independent proof of the law of effect as asserted by Thorndike. The theory of isolation presented would interpret the Thorndike effect as a result of different degrees of isolation of responses neighboring upon a key isolated response—these different degrees of isolation being due to the differing degrees of association of the neighboring responses with the key response. Naturally, as indicated before, other conditions than isolation which are favorable to learning must also be present in order for the gradient to appear.

Summary

Experimental evidence is presented to show that the influence of a satisfying after-effect in enhancing reproduction of a response in serial learning is not necessarily attributable to some mysterious 'strengthening force' which it exerts on the response, as asserted by Thorndike. The enhancement of reproduction may be explained more simply as a result of the tendency of a satisfying after-effect to isolate the response which it follows. In these experiments, isolation of a response, whether by a satisfying after-effect or by some other means, resulted in enhanced repetition of it when other conditions favorable to learning were present. The degree of enhancement was seen to be roughly proportional to the extent of isolation of the response.

The Thorndike effect was shown to appear under a variety of conditions beside the one of wrong responses neighboring upon a right response which has been explored before. The Thorndike effect is interpreted as the result of different degrees of isolation of responses neighboring upon a key isolated response—their different degrees of isolation being due to their differing degrees of association with the key response.

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REHEARSAL AND GUESSING HABITS AS SOURCES OF THE 'SPREAD OF EFFECT'

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Purpose of the Study

The purpose of the study was to test a hypothesis to account for the 'spread of effect,' a phenomenon first reported by Thorndike (**8**).

In Thorndike's first study and in typical subsequent studies, word-stimuli in a fixed order are consecutively presented to the *S* at a rate of about one every three sec., and the *S*'s task is to learn the correct number-response that is to be associated with each word stimulus. In response to each word the *S* guesses a number within a limited range, say from one to ten. Each time his guess corresponds with the *E*'s pre-determined number the *E* says 'right,' and each time it fails to correspond the *E* says 'wrong.' The *S* is instructed to try to learn his correct guesses and repeat them when the same word is given again in successive presentations of the fixed list.

Under these conditions the *S* tends to increase his number of correct responses on successive times through the list, new correct guesses being added as the experiment continues, and a sizeable proportion of previous correct guesses being remembered and repeated. This result in itself—the repetition of correct responses—was not surprising, since it corresponds to the typical rote-learning findings. The striking result obtained by Thorndike and others (**1**, **5**, **9**) was that in addition the *S* tended to repeat the responses that were wrong, but which were adjacent to a response rewarded with 'right,' this tendency decreasing with greater remoteness of the error from the correct response.

Thorndike (**8**, **9**) interpreted this finding as the 'spread' of the reinforcing effect of reward to adjacent stimulus-response bonds, and in line with his 'law of effect' concerning the reinforcing effect of rewards, he termed the phenomenon the 'spread of effect.' He presented the results as proof of the automatic reinforcing action of rewards, the proof presumably being that adjacent errors were more often repeated despite the fact that the *S* was motivated by the instructions to learn only correct responses.

[1] The data for this study were obtained in 1942 while the authors were at Yale University.

The present study was undertaken to test a hypothesis that might account for these findings in terms of the simple concepts of rehearsal and distraction and their effects on learning. After the experiment was completed an even simpler hypothesis was conceived in terms of the *S*'s guessing habits. Although the experiment was not set up to test this latter hypothesis, an analysis of the data at hand gives it a great deal of support as a major factor in the 'spread of effect.' The results for both hypotheses will be shown.

The Rehearsal–Distraction Hypothesis

This is the hypothesis which the study was designed to test. Essentially this hypothesis is that when the *E* indicates a correct guess by saying 'right,' the *S*'s attention is shifted from learning what is wrong to learning what is right, with consequent decrease in his remembrance of incorrect guesses adjacent to reward. The *S* has two learning tasks: to repeat correct responses the next time through the list and to *avoid* repeating incorrect responses the next time through the list. According to the hypothesis, saying 'right' causes the *S* to rehearse silently (and in fact sometimes audibly) the correct word-number pair, and this rehearsal functions as a *distraction* that interferes with his later recall of wrong word-number pairs immediately preceding and especially immediately following the correct response. If the *S* cannot, on the next time through the list, recall what errors he made during the period that he was occupied with rehearsing the correct response, he will be more likely to repeat the same errors than if he can recall these errors.

This hypothesis makes no assumptions as to the absolute level of repetition to be expected at any point on the gradient, whether near to reward or remote from reward. It merely postulates that, whatever the initial tendency to repeat errors, the instructions motivate the *S* to avoid such repetition, and the frequency of this repetition will, to the extent that he can learn what is wrong, be lower for errors remote from the rewards and their distracting effects.

Proposed Test of the Rehearsal–Distraction Hypothesis

The proposed test of this hypothesis was to provide a distraction at all times during the brief interval between stimulus-response pairs and compare the results with those of the typical procedure. If the distracting effect of rehearsal of correct responses is the source of the gradient of repetition of errors in the typical procedure, this gradient should be minimized or eliminated entirely by providing a distraction after all responses, whether adjacent to or remote from rewards. Moreover, the hypothesis implies that the reduction in the gradient

should come about by an *increase* in the level of repetition of errors remote from reward, and that the level of repetition of correct responses should decrease because of the interference with the rehearsal of these responses.

Experimental design.

The design of the experiment involved using each *S* as his own control in order to reduce variability in results due to individual differences and in order to warrant the statistical treatment of the data in terms of responses rather than in terms of individuals. Each *S* was given half of his trials under the distraction conditions and half of his trials under 'typical' conditions, that is, with no distraction (once through the list of word-stimuli constitutes a trial). Two trials with the distraction conditions were alternated with two trials of the no-distraction conditions until a total of six pairs of trials had been accumulated, three pairs under distraction and three pairs under no distraction. To balance for stage of learning, half of the *S*s were started with a pair of distraction trials and half of the *S*s were started with a pair of no-distraction trials.

The distraction used was 'naming opposites.' During the interval between the *S*'s guess and the presentation of the next word in the list, the *E* would call out a word such as 'soft,' and the *S* was required to answer immediately with a word of opposite meaning. Since a total of only four sec. was allowed for the presentation of the list word, the *S*'s numerical response, the *E*'s presentation of the distraction word, and the *S*'s opposite response, the time interval was well filled.

Under the no-distraction conditions the *E* merely said 'right' if the *S* gave the pre-determined number to a word; under distraction conditions the *E* said 'right' for correct responses, but in addition presented the word for 'naming opposites' during the interval before the next word-stimulus. The omission of 'wrong' for incorrect responses was a deviation from Thorndike's typical procedure, but this deviation has been shown (1) to give essentially the same results.

Apparatus and experimental procedure.

The word-stimuli for the numerical responses consisted of 25 English monosyllables on a continuous 35 mm. film strip projected by means of an Argus film projector onto a ground glass plate covering a small aperture in a wooden screen which faced the *S*. A telechron timer activating a solenoid-driven ratchet presented these word-stimuli at a fixed time interval of four sec. This apparatus has been described previously (4). The word-stimuli were photographed in a fixed order, and this fixed list was repeated six times on the film strip. The strip was spliced into a single loop, so that no special cues were given the *S* at the beginning and end of the list. The list was presented 13 times in all to each *S*.

The instructions to the *S* were:

> This is an experiment in guessing numbers to words and remembering the correct numbers; it is not an intelligence test. You will see a series of words appear one by one in this slot (indicating aperture). To each word you are to guess a number from one to eight—only one number is to be guessed to each word. Each word has a correct number which I have given it, and if you guess this right number I shall call out 'right'; if you do not guess the correct number I shall say nothing. If you guess one right, try to learn and remember that the number goes with that particular word.
>
> Do not use any guessing system such as saying 'six' to all the words until you get one right. You will get more correct by guessing at random.
>
> Occasionally I shall call out words like 'long' and 'cold' and so forth. When I do this you are to answer by calling out the word that means just the opposite. If you can't think of an opposite just say the first word that comes to mind.
>
> Remember that I will say 'right' only when the number you say is correct so don't give an opposite to the word 'right.' Remember there are two tasks: you must guess a number from one to eight to each word appearing on this screen ,and learn the ones to which I call out 'right,' and you must call out opposites to words I say. Continue until I say 'stop' which will be in about 20 minutes.

The *S* was then asked if he had any questions and was told not to ask questions after the experiment started.

Three number-keys were used for the list of 25 words in order to minimize any tendencies for initial word-number associations to influence the frequency of repetition in a particular part of the list. The number and the particular key used for a given *S* were selected at random.

The words for the distraction task of 'naming opposites' were a list of 100 common English words such as *sick*, *poor*, *dark*, *hard*, *pretty*, *absent*, etc. with fairly common opposites. On the fifth distraction trial the same list was started over again.

The *S*s were a volunteer group of Yale undergraduate and graduate students. A total of 31 *S*s was used, of which 16 began the experiment under distraction conditions and 15 began under no-distraction conditions.

The *E* employed a mimeographed tabulation sheet with the stimulus-words and the number key entered on the sheet. Spaces were provided for recording by hand each number-response of the *S* for each word in each trial. No record was kept of the *S*s' responses to the distraction stimuli.

Analysis procedure

There are a number of procedures that have been used or could be used to analyze the results for 'spread of effect.' The problem is especially important, since certain methods of analysis inherently yield spurious gradients. One difficulty is that previous writers have not always described their scoring procedures completely or adequately. The authors desired to use the most typical scoring procedure so that the results would be directly relevant to previously reported findings. The procedure outlined below seems to be the most typical and was the one used with minor modifications (as noted).

Each response in the second trial of a pair was characterized according to two properties:

(1) Whether it was a repetition or a non-repetition of the response to that word on the preceding time through the list.

(2) The proximity to reward of the response to the same word on the preceding trial through the list. That is, was the response on the preceding trial rewarded or unrewarded, and, if unrewarded, was it equidistant between two rewards or was it closer to a preceding reward ('after' gradient) or to a following reward ('before' gradient), and how many word-number units away was the nearest rewarded response?

Using this characterization of responses the results are cumulated separately for rewarded responses and for responses one, two, three, four, and five or more, before and after a reward. The responses equidistant from a reward are either ignored or treated separately as 'betweens' (9). (In this investigation they were ignored.) The responses five or more removed are grouped together to form a presumed 'baseline' of repetition of responses remote enough before and after a reward to be outside the influence of the 'spread of effect.' (In the present study responses five or more after a reward were tallied separately from those five or more before a reward.)

Percentages are then computed for a given position with respect to reward by dividing the number of repetitions at that position by the total number of repetitions plus non-repetitions at that position.

Results of the Test of the Rehearsal and Distraction Hypothesis

Table I shows the results obtained under typical conditions (no external distraction) compared with those obtained under conditions of distraction during the interval between word-number pairs. In Table I the results are combined for errors one and two removed from 'rights' and for errors three or more removed from 'rights.' These combinations were made in view of the unreliability of the percentages at individual points.

It can be seen in Table I that, whereas the rewarded responses were repeated less often under conditions of distraction, the unrewarded responses were more often repeated under this condition in

TABLE I

EFFECT OF DISTRACTION ON THE 'SPREAD OF EFFECT'

A comparison of the percentage of repetition of responses in the designated positions with respect to reward, under conditions of distraction (*D*) and under conditions of no distraction (*No D*). '*N*' refers to the total number of responses on which each percent is based.

		3 and more Before	1 and 2 Before	Reward	1 and 2 After	3 and more After
D	*N*	446	438	441	431	382
	%	20.8	20.8	55.6	23.0	16.8
No D	*N*	438	436	421	433	349
	%	16.9	20.2	64.8	21.5	18.0

three of the four comparisons shown. This aspect of the findings conforms to the expectations based on the rehearsal and distraction hypothesis, although none of the comparisons shown is significantly different beyond the five percent level except that of the rewarded position (C.R. = 2.7).

The tendency toward greater repetition of errors under distraction conditions shown in Table I was exaggerated in the early trials (presentations of the list) and disappeared entirely in the later trials. The results for the first four trials (one pair under no distraction and one pair under distraction) are shown below in Table II.

TABLE II

EFFECT OF DISTRACTION IN THE EARLY TRIALS

A comparison of the percentage of repetitions in the designated positions with respect to reward, under conditions of distraction (*D*) and conditions of no distraction (*No D*) for the first pair of trials under each of the two conditions. '*N*' refers to the total number of responses on which each percent is based.

		3 and more Before	1 and 2 Before	Reward	1 and 2 After	3 and more After
D	*N*	230	130	104	122	152
	%	19.1	20.8	36.5	26.2	18.4
No D	*N*	220	111	93	119	164
	%	13.6	18.0	43.0	22.7	14.6

Although the *N*'s are much smaller and the percentages therefore more unreliable, in some respects the results shown in Table II are more valid than those shown in Table I. For one thing, the *S*s may have adapted to the distraction so that it was less effective in the later trials. Even more important, however, the early trials are less subject to the selection effects in a long series of trials due to the increasing frequency of rewards, whereby most of the data on errors close to rewards come from the later trials where rewards are close

together and most of the data on errors remote from rewards come from the early trials where rewards are farther apart.

In any case the data in both Table I and Table II fail to give much support to the rehearsal and distraction hypothesis. While they do indicate a greater level of repetition under distraction, they do not indicate an appreciable flattening of the gradient. The 'before' side of the gradient was more flat under distraction, but the 'after' side, to which the authors attach more significance, was just as steep under distraction.

However, it is worth pointing out that the results indicate that the same variable (distraction) had opposite effects on the repetition of correct responses and the repetition of errors. This argues against Thorndike's interpretation that the gradient of repetition of errors reflects the same phenonemon as the learning of correct responses. In the early trials shown in Table II the greater repetition of errors under distraction was significant beyond the five percent level (C.R. = 1.9). Another way of looking at the greater repetition of errors under distraction is that it indicates, both for errors adjacent to reward and for errors remote from reward, that the learning process under way is the avoidance of errors rather than the repetition of errors. Thus, a distraction, which normally interferes with learning and which was shown to interfere with the learning of the correct responses, interfered with the *avoidance* of wrong responses.

The Guessing Sequence–Hypothesis

The hypothesis that developed after the data had been gathered may be called the guessing-sequence hypothesis. According to this hypothesis the *S* guesses numbers in a sequence that is to a certain extent predictable. If he has just guessed 'four,' his next guess is more likely to be 'three,' for example, than any of the other possible numbers, depending on the particular *S*'s predisposition. If his response, 'four', is repeated to the same word the next time through the list for any reason whatsoever, 'three' is also likely to be repeated to the following word in the list merely because he most often guesses 'three' after 'four.' Since the correct responses tend to be remembered and repeated, the same sequence of numbers is likely to be elicited in the same positions following this number. If the *S*'s number sequences were invariable, he would repeat his errors after a rewarded response exactly as often as he repeats the rewarded response. To the extent that his number sequences are not invariable, he repeats his errors to a lesser extent, and the more removed the error's position after the number 'anchored' by saying 'right', the less likely it is to be repeated in that position the next time through the list even though the rewarded number is repeated.

It will be noted that this hypothesis will account only for a gradient of repetition *after* the rewarded response, whereas Thorndike (9) has concluded that the effect of reward is to increase repetition of errors before as well as after the reward. However, the typical result (1, 9) shows the repetition of errors to be greater after correct responses than before, and Tilton (10) has shown that in the typical method of assembling the data the responses recorded in positions close before reward are also most frequently close after reward, which gives rise to a spurious 'before' gradient. This problem will be discussed in more detail later.

Results of Tests of the Guessing–Sequence Hypothesis

Since the experiment was not designed to test this hypothesis, tests had to be devised *ex post facto* from the data at hand. The simplest test seemed to be merely to divide all rewarded responses into those that were repeated on the next trial and those that were not, and determine the 'spread of effect' around the two different classes of rewards. According to the hypothesis it is not the rewards, but the *repetition* of rewarded responses that gives rise to the greater repetition of succeeding errors. The results of this test are shown in Table III.[2]

TABLE III

Effect of Repetition of 'Rights' on 'Spread of Effect'

A comparison of the repetition of errors around rewarded responses that were repeated, and around rewarded responses that were non-repeated. '*N*' refers to the total number of responses on which each percent is based.

		3 and more Before	1 and 2 Before	Reward	1 and 2 After	3 and more After
Repeated	*N*	356	472	408	467	307
	%	17.4	22.0	100	23.5	19.9
Non-repeated	*N*	347	356	303	379	368
	%	21.0	17.4	0	19.3	17.7

Table III shows definite evidence for a gradient in the case of 'rights' that were repeated and little evidence for a gradient in the case of 'rights' that were not repeated. Thus, the gradient of repeated errors around reward appears to depend not on the reward, but rather upon the repetition of the rewarded response. These results support the guessing-sequence hypothesis.

For comparison with the results of the rehearsal and distraction

[2] The number of responses on which Table III is based is somewhat less than in the case of Table I. This is due to the fact that no cases were used in testing this hypothesis in which the reward occurred in one trial and the error occurred in another.

hypothesis shown in Table II, the results of the test of the guessing-sequence hypothesis are shown below in Table IV for only the first four trials.

TABLE IV

EFFECT OF REPETITION OF 'RIGHTS' IN EARLY TRIALS

A comparison of the repetition of errors around rewarded responses that were repeated and around rewarded responses that were non-repeated, using only the first pairs of distraction and no-distraction trials. '*N*' refers to the total number of responses on which each percent is based.

		3 and more Before	1 and 2 Before	Reward	1 and 2 After	3 and more After
Repeated	*N*	140	97	71	101	102
	%	17.2	25.8	100	28.7	16.7
Non-repeated	*N*	158	127	106	130	177
	%	17.1	12.6	0	18.5	15.8

It can be seen in Table IV that the gradients obtained for repeated 'rights' were steeper and the level of repetition of errors adjacent to non-repeated 'rights' was lower, as compared with the results for all trials.

The results shown in Tables III and IV are based on the data both from the no-distraction conditions and the distraction conditions. This complicates the findings with a variable that is not relevant to the test of the guessing-sequence hypothesis as the explanation of the results obtained in a typical 'spread of effect' study. The results for the data from only the typical conditions (i.e., no distraction) are perhaps even more clear-cut. The findings are shown below in Table V for all pairs of no-distraction trials.

TABLE V

EFFECT OF REPETITION OF 'RIGHTS' WITH NO DISTRACTION

A comparison of the repetition of errors around rewarded responses that were repeated and around rewarded responses that were non-repeated, using only the data obtained under no distraction. '*N*' refers to the total number of responses on which each percent is based.

		3 and more Before	1 and 2 Before	Reward	1 and 2 After	3 and more After
Repeated	*N*	190	260	219	257	184
	%	16.3	21.5	100	24.1	21.2
Non-repeated	*N*	175	157	136	173	176
	%	16.0	16.6	0	16.8	17.0

It can be seen in Table V that under the typical conditions for studying 'spread of effect' there was no evidence whatsoever for a gradient of repetition of errors around 'rights' that were not repeated. The set-up was not exactly typical, of course, since dis-

traction trials were interspersed between the pairs of no-distraction trials on which the findings in Table V are based. However, the findings definitely indicate that the repetition of the rewarded responses, rather than the mere occurrence of rewards, is the critical factor in the 'spread of effect.'

While the results shown in Tables III, IV, and V all show differences in the direction expected from the guessing-sequence hypothesis, none of the differences is very reliable. An additional check was made in order to get a larger number of cases for a statistical test. This check utilized all pairs of trials, regardless of experimental conditions. It will be remembered that the experiment utilized alternate pairs of trials under distraction conditions and no-distraction conditions. The results shown in Tables I through V are based on the pairs of trials having the same experimental condition in each trial of the pair. The additional check involved obtaining, in addition, results from pairs of trials made up of adjacent distraction and no-distraction trials.

This check was made only for errors in the position of one step after a 'right.' This is the position most relevant to the guessing-sequence hypothesis and in Thorndike's studies (**9**) it appears to be the position giving the greatest repetition of errors. All such errors were used, including those immediately followed by another reward (these 'betweens' were omitted in the preceding analyses because they were equidistant from two rewards). The results of this check are shown below in Table VI.

TABLE VI

EFFECT OF REPETITION OF 'RIGHTS' ON IMMEDIATELY FOLLOWING ERRORS

A comparison of the repetition of all errors one after a 'right,' for repeated 'rights' and for non-repeated 'rights,' for all pairs of trials, according to the experimental conditions of no distraction (*No D*) and distraction (*D*). '*N*' refers to the total number of responses on which each percent is based.

Experimental Conditions of the Pairs of Trials		Repetition of Errors One after:	
		Repeated 'Rights'	Non-repeated 'Rights'
No D, No D	*N*	194	129
	%	24.7	15.5
No D, D	*N*	210	136
	%	27.6	17.6
D, No D	*N*	190	116
	%	25.3	22.4
D, D	*N*	158	150
	%	23.4	20.0
Total, all pairs	*N*	752	531
	%	25.4	18.8

It can be seen in Table VI that the difference is in the direction expected from the guessing-sequence hypothesis for each of the four combinations of experimental conditions. The difference of 6.6 percent for the total of all pairs has a critical ratio of 2.8 ($P < .01$).

It should be pointed out that the results on the guessing-sequence hypothesis shown in Tables III to VI are independent of individual differences in the particular sequences of numbers likely to follow any given number. The procedure of dividing the rewarded responses into 'repeats' and 'non-repeats' allows each individual's particular guessing habits to maximize the repetition of errors after repeated 'rights.'

However, some general tendencies were observed that seemed to be characteristic of the group over and above each individual's personal guessing habits. Only crude analyses were made on these observations, partly because it was felt that the data did not warrant close analysis on these points because the admixture of distraction in the experimental conditions would detract from the generality of the findings. The analyses that were made indicate two general tendencies in the guessing sequences of the group of 31 *S*s:

1. A distinct tendency to avoid, as the response to the next word stimulus, the number given to the preceding 'right.' For example, in the first four trials the number guessed one after a 'right' was different from the preceding correct number in 94 percent ($N = 376$) of the cases.

2. A tendency to guess, in response to the word-stimulus one after a 'right,' a number close to the rewarded number. For example, in the first four trials when the rewarded number was 'four' the most frequent digits guessed in the next position were 'three,' 'five,' and 'six.' These three digits accounted for 65 percent ($N = 76$) of the succeeding responses whereas they should account for only 38 percent if the *S*s had guessed at random. This tendency was strongest in the middle range of digits used and diminished for the extremes of 'one' and 'eight.'

The second general tendency above—the tendency to guess a number close to the preceding number—suggested a further check of the implications of the guessing-sequence hypothesis. This tendency, together with the hypothesis, implies that non-repeated 'rights' will have a differential effect on the repetition of errors depending on the extent to which the wrong digit on the second trial of the pair differs from the correct digit rewarded on the first trial of the pair. For example, suppose 'four' in response to a given word-stimulus is rewarded with 'right,' but the next time through the list the *S* fails to repeat this correct response and instead says 'six.' This nevertheless leaves a fair probability that he will say 'five' in the following

position on both trials, since 'five' is fairly commonly elicited in the position one after either 'four' or 'six.' However, if the rewarded response is 'four' and the next time through the *S* says 'eight,' no common response is likely in the poisition one after such a non-repeated 'right.'

To check this prediction, non-repeated 'rights' were divided according to the difference between the correct digit on the first trial and the incorrect digit to the same word on the next trial of the pair, and the repetition of errors in the position one after the non-repeated 'rights' was determined. According to the guessing-sequence hypothesis and the above-mentioned group tendency, non-repeated 'rights' in which the two digits are greatly different should be less likely to be followed by repeated errors. The percentages of repetition were:

Difference of 1 or 2: 19.8% (N = 313)
Difference of 3 or 4: 18.3% (N = 158)
Difference of 5 to 7: 15.0% (N = 60).

This descending frequency of repetition, depending on the size of the difference between the two digits in the non-repeated 'right,' is in the direction predicted by the guessing-sequence hypothesis.

Discussion of Results

The results of the study constitute definite evidence against Thorndike's interpretation of the 'spread of effect.' It was shown that the efficacy of rewards at producing the 'spread' depended on whether or not the rewarded response was repeated.[3] Thus, the spread effect appears to depend not on any automatic reinforcing effect of rewards, but rather on the fact that the *S* tends to make his choices in a predictable sequence, the major effect of reward being to increase the repetition of correct responses.

The guessing-sequence hypothesis receives corroboration from previous studies, mainly from a study done by Muenzinger and Dove (**5**). These *E*s set as one of their problems to determine whether the spread was due to the uncertainty of the *S* as to just where the correct response was located in the list. They taught the *S*s in advance some correct responses, and in the experiment that followed they rewarded only these responses in the list, thereby ruling

[3] One of the correlates of repeated 'rights' that should be controlled before the effects are assigned to the repetition is the reward on the second trial of the pair which is absent in the case of non-repeated 'rights.' An analysis was made of the repetition of all errors one after non-repeats that were right on the second trial of the pair. The percentage was 19.8 (N = 620), which is very close to the 18.8 percent obtained for non-repeats that were right on the first trial of the pair. The difference of 5.6 percent between the figure of 19.8 percent and the 25.4 percent obtained for repeated 'rights' has a critical ratio of 2.5 (P = .01).

out the factor of uncertainty. Under these conditions the *Ss* repeated the pre-learned correct responses 100 percent of the time, and the gradients of repetition of following errors obtained were considerably higher and steeper than in their control group tested under the typical conditions. This result fits in with the guessing-sequence hypothesis, which hinges on the effect of reward at increasing the *repetition* of rewarded responses.

Results in line with this hypothesis were obtained in a study by Wallach and Henle (**11**), in a set-up in which the *S* thought he was participating in an experiment in 'mental telepathy' and was told that a response to a word-stimulus that was right on one trial would not necessarily be right on the next trial. Under these conditions there was no tendency to repeat 'rights' any more than 'wrongs,' and there was correspondingly no gradient of repetition of errors adjacent to the infrequently repeated 'rights.'

Further corroboration is obtained from a finding reported by Tilton (**10**) who noticed a tendency for *Ss* to repeat 'blocks of the pattern,' that is, to repeat a *sequence* of responses as opposed to single responses. Tilton used syllables rather than numbers as responses, but he apparently found a tendency for a given response to influence the succeeding guesses, as is implied by the guessing-sequence hypothesis. Tilton suggested that the gradient of repetition of errors may be due to the reinforcement of such 'blocks,' which he reports occurred in decreasing frequency with increasing length of 'block.' The notion of reinforcement of 'blocks' is not necessary, however, since if the *S* is pre-disposed to giving 'blocks' of responses in a given sequence, all that is required is that 'rights' will sometimes be the first response in a 'block.'

Farber (**2**) reported an incidental finding that also supports the guessing-sequence hypothesis. Farber used a punchboard maze which allowed the *S* a choice of six manual responses at each choice-point in the maze, the choice-points corresponding to the word-stimuli in the typical 'spread of effect' study. Farber controlled the occurrence of reward so that the *S* was always rewarded at certain choice-points and always failed to receive reward at others, regardless of the responses given at a particular choice-point. He confirmed the typical 'spread of effect' findings, but reported a tendency on the part of the *Ss* to choose, as 'errors' after a reward, points spatially more and more removed from the rewarded response in successive choices after reward. At each choice-point the punch-board choices were arranged in a hexagon, and the *Ss* apparently chose an opening close to the preceding rewarded opening in the response immediately following reward, but chose more and more remote openings in the succeeding 'errors.' This finding implies a definite guessing-sequence

that would favor repetition of errors after rewarded responses that are repeated.

As was mentioned previously, the guessing-sequence hypothesis will account only for the gradient of repetition of errors *after* 'rights.' Since gradients are reported before 'rights,' this is a difficulty in the way of interpreting all of the results in terms of this hypothesis. However, Tilton (**10**) has cast doubt on the existence of a true 'before' gradient, not only because the 'before' gradients reported have been slight, but also because he was able to show that the gradient before rewards can be generated by the gradient after rewards. Thus in the typical study an error that is recorded as one before a 'right' is most often also two *after* a 'right,' although the latter fact is not recorded. This is due to the fact that errors are most frequently surrounded by nearby rewards and least frequently surrounded by remote rewards. Thus, in the present study, the most frequent situation was one error between two rewards, the next most frequent was two errors between two rewards, and so forth. It can be seen, therefore, that responses recorded as one before a reward are most often one before and two after, next most often one before and three after, etc. Similarly, it can be seen that responses recorded in more remote positions before reward will be further out on the 'after' gradient. For example, a response recorded as three before a reward can be no closer than four after a reward. Therefore, if there is any 'after' gradient whatsoever, an artificial 'before' gradient will be obtained in the typical study and analysis procedure.

It should be pointed out that the 'before' gradients shown in Tables III, IV, and V are subject to a selection factor that raises the level of repetition of errors before repeated 'rights.' Thus, in sorting out all of the repeated 'rights,' those 'rights' that are repeated by chance are also included. In line with the guessing-sequence hypothesis, repetition of a 'right,' especially in the early trials, is most likely to occur when the preceding error happens to have been repeated. Therefore, the selection of all repeated 'rights' maximizes the inclusion of cases in which the immediately preceding error had been repeated. This selection factor probably accounts in part for the 'before' gradients shown in Tables III, IV, and V.

The question might be raised as to whether the guessing-sequence hypothesis is relevant to 'spread of effect' studies in which the multiple-choice responses are not numerical and therefore might be less prone to be elicited in some sort of a sequence in which the preceding guesses influence the following guesses. For example, in some of the studies reported by Thorndike (**9**), non-numerical responses were used such as English words, marking positions in visual patterns, etc. As another example, Brandt (**1**) employed the

manual response of pressing typewriter keys arranged in a row. However, the findings of Tilton (**10**) and Farber (**2**) that have already been discussed indicate that guessing-sequences operate in at least two examples of non-numerical responses, namely, for syllables and for a manual response, respectively.

Another question that should be raised is the relevance of guessing-sequences to studies of the 'spread of effect' with animal subjects. Muenzinger, Dove, and Bernstone (**6**) and Thompson and Dove (**7**) have utilized the term 'spread of effect' in connection with gradients of better learning by rats of *correct* responses immediately before and after reward in a situation in which errors are corrected before the animal proceeds to the next choice. This is not analogous to the typical 'spread of effect' study in which *errors* are repeated in a situation in which the individual cannot go back and correct his error. Jenkins (**3**), however, obtained gradients of repetition of choices before and after reward points in a dichotomous-choice maze with rats. The findings of this study are complicated by the animals' tendencies toward anticipatory and perseverative performance of the rewarded response as shown by Jenkins. No finding strictly comparable to those of human 'spread of effect' studies are available at the animal level. Nevertheless, it seems probable that animals' choices, in a free multiple-choice situation, would be influenced by the preceding choice, which is all that is assumed by the guessing-sequence hypothesis.

Summary

1. This study was undertaken to investigate the effects of distraction on the 'spread of effect' reported by Thorndike and others. It was postulated that silent rehearsal of correct responses interferes with learning to avoid incorrect responses that are adjacent to reward. The predictions were that experimentally imposed distraction would reduce the frequency of repetition of correct responses, and that it would raise and flatten the gradient of repetition of errors by interfering with the learning of what responses were wrong.

2. It was found that, while distraction decreased the repetition of rewarded responses and increased the over-all repetition of errors as predicted, it did not flatten the slope of the gradient as expected by the hypothesis.

3. However, analysis of the data strongly suggested that rewarded responses give rise to the gradient of repetition of errors depending on whether or not the rewarded responses are repeated. Correct responses that were not repeated were accompanied by a lower level of repetition of errors and by absence of a gradient of repetition of errors adjacent to reward, as contrasted with a higher

level of repetition of errors and the presence of a gradient of repetition in the case of rewarded responses that were repeated.

4. These latter findings support the hypothesis that the 'spread of effect' is due, not to the automatic action of reward as postulated by Thorndike, but rather to the S's tendency to guess, from the choices provided, in a sequence in which the preceding choice influences the following choice. Thus, the effect of the reward appears to be due solely to the greater *repetition* of rewarded responses, which insures that the errors following reward will be frequently preceded by the same response, i.e., will have a common antecedent stimulus. Evidence against the existence of a true gradient of errors before reward is discussed.

5. Findings of other investigators are shown to support this guessing-sequence hypothesis.

(Manuscript received November 19, 1945)

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THE ABILITY TO JUDGE PITCH[1]

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Introduction

This investigation is designed to afford a more complete account of individual differences in pitch-judging ability than hitherto has appeared. Studies previously made in this field have been confined to the judging performance of very talented individuals (**1**, **2**, **3**), or describe attempts to improve pitch-judging ability by training (**4**, **5**, **7**).

Findings related to the present study are: (1) high accuracy in judging the pitch frequency of tones obtains from a select group of trained individuals derived largely from the musical population, and (2) the degree of accuracy is conditioned upon the timbre-quality and location of the tone in a series of pitch frequencies such as the piano keyboard. Baird (**3**) found that piano notes were easier to identify than tones produced by tuning forks. Petran (**6**) reported that students of music who possessed a high degree of pitch-judging ability more often judged correctly piano notes located in the middle region of the scale than very high or very low notes. Wedell (**7**), however, found that his *unmusical observers*, when judging *pure tones*, were less accurate in the middle of a series of tones, with the size of the error gradually decreasing toward the ends of the scale.

In view of these diverse findings derived from experiments characterized by differences in subjects and stimuli employed, an inquiry which would embody the several features in a single experimental setting appeared warranted.

The Present Study

To achieve this aim, musical and unmusical observers were asked to judge the pitch of piano notes *and* pure tones. Thus, direct comparisons between the performances of two groups were made possible, and effects produced by differences in timbre-quality of tones could be noted as well.

Thirty-seven individuals were required to identify by note-name and octave-position a series of 24 piano notes, using a schematic keyboard diagram for reference. These notes were selected

[1] From the Psychological Laboratory at Princeton University.

so as to sample the entire piano keyboard range and were presented in the order shown in Fig. 1. A record of the judgments was kept for each note presented. The piano notes were struck so as to produce an intensity great enough to be heard distinctly, held for a period of two sec. (the maximum duration of the highest-pitched notes), and then damped.

Two months later 119 individuals were required to identify a series of pure tones of the same pitch-frequencies as the piano notes. This series was presented in the reverse of the serial order in Fig. 1, to offset the possibility that some of the individuals who had previously identified piano

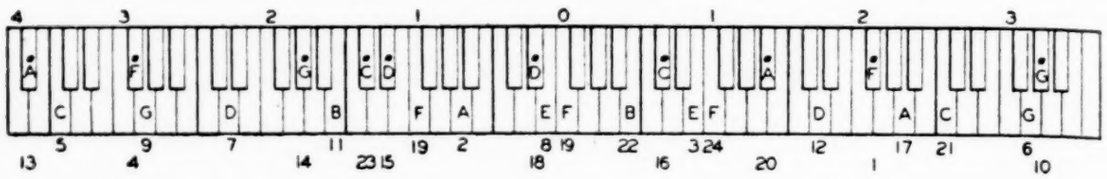

FIG. 1. Keyboard arrangement of the 24 notes of the piano series. The number beneath each note indicates its order of presentation in the series.

notes might remember the order of presentation and spuriously raise their level of performance. The pure tones were generated electrically by means of a Western Electric 6010-B vacuum tube oscillator. With this instrument the amount of overtones could be kept below 1.5 percent and the intensity of the pure tones could be set at a level approximately 40 decibels above threshold at 1000 cycles. The pitch-frequencies of the pure tones were with three exceptions identical with the piano notes.[2] Presentation No. 19 of the piano series was F in the first octave below middle C, whereas presentation No. 19 of the pure-tone series was F in the middle C octave. Also, presentations 5 and 13 (the two lowest notes) of the piano series were omitted from the series of pure tones, reducing the number of pure tones to 22.

Before entering upon a discussion of the results, it is important to view the characteristics of the individuals selected as observers. Since one aim of this inquiry was directed toward a comparison of ability between disparate groups, namely musical and unmusical observers, consideration was given to the problem of determining the criteria by which to define the two groups. It seemed advisable, in view of previous reports, to select individuals claiming to possess highly developed pitch-judging ability to constitute the musical observer group. Hence all musical observers were students of music and all believed their sense of pitch was well developed. The unmusical observers were selected on the basis of opposing characteristics. None of the unmusical observers were students of music, and none claimed to be able to judge pitch. Selection of observers by these criteria permitted determination of the upper and lower levels of ability, and in addition made possible a meaningful comparison of the performances of the two groups.

Having defined the general characteristics of the observers, it is necessary to note the experimental procedure followed in testing pitch-judging ability. Of the 37 observers who judged piano notes, 20 were students of music who claimed a well-developed sense of pitch, while the remaining 17 were liberal arts students who claimed no ability to judge pitch. These two groups are designated as Group 1 (musical observers) and Group 3 (unmusical observers), respectively. Similarly, the 119 observers who judged pure tones were selected to represent separate populations. Fifteen observers who had identified piano notes were available to judge pure tones. All of these observers were students of music who had claimed ability to judge pitch. The remaining 104 observers were students of liberal arts, none of whom claimed pitch-judging ability. These two groups are designated as Group 2 (musical observers) and Group 4 (unmusical observers), respectively. It might well be noted at this point that the selection process of this inquiry not only permitted determination of limits of ability, but also squarely posed a test of the assumption that ability to judge pitch is confined to certain types of individuals.

RESULTS AND INTERPRETATION

The bearing of the foregoing discussion upon the results may be considered profitably from four approaches: first, through an analysis

[2] The method of calculating frequencies in the equal temperament scale is given by G. F. A. Harper in 'The principles underlying the tuning of keyboard instruments to equal temperament,' *J. acoust. Soc. Amer.*, 1937, 8, 243–56.

of the number of correct judgments; secondly, through an analysis of the incidence of error in judging the correct octave of accurately named notes: thirdly, through an analysis of extent of error; and fourthly, through analysis of the place on the scale of most and least accurate judgments.

Analysis of correct judgments will yield data which indicate the range of ability for all observers and will also indicate the relative accuracy between the performances of musical and unmusical observers. Octave-interval error analysis will show individual differences in ability to judge the correct octave position of those notes that have been accurately named. Error analysis is also important in

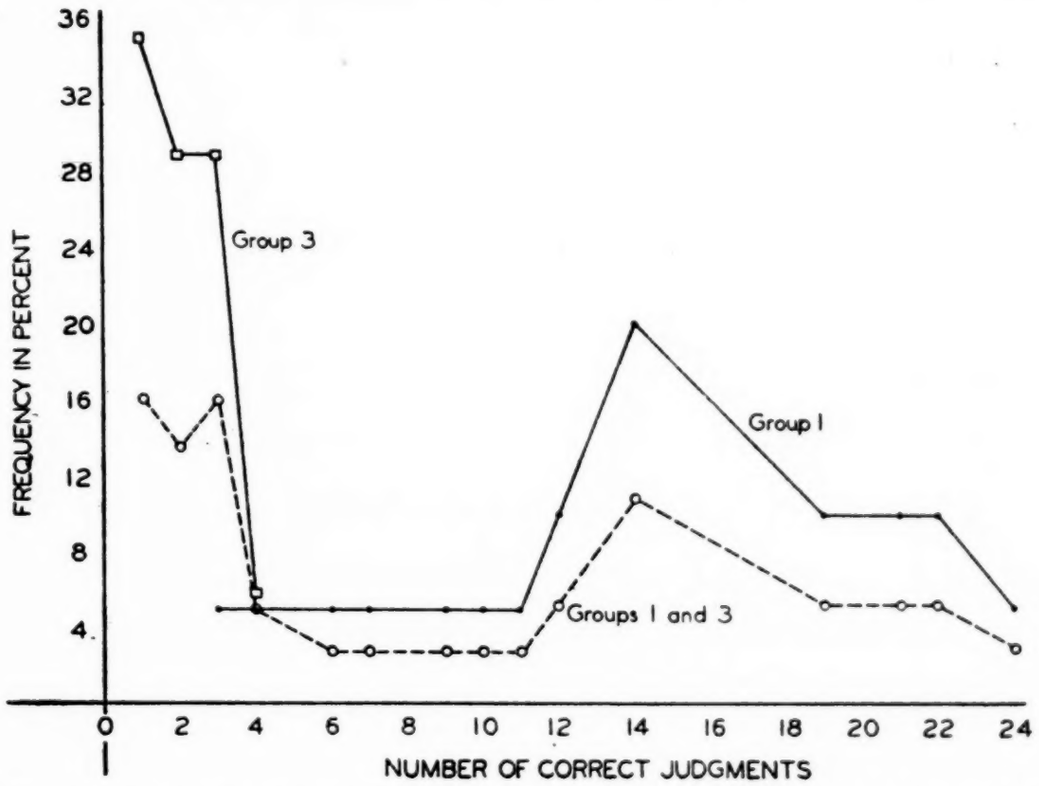

FIG. 2. The number of correct piano-note judgments achieved by musical observers (Group 1) and unmusical observers (Group 3). Performance of both groups combined is shown by the broken curve.

order to demonstrate the range of error distribution of incorrectly judged tones, and analysis of place of most and least accuracy is necessary to a critical appraisal of the characteristic tendencies of musical and unmusical observers hitherto reported.

Fig. 2 shows the percent of correct judgments (disregarding errors in judging the octave position of the notes) achieved by the 37 observers who identified piano notes. A comparison of the curves of the distributions of correct judgment revealed that muscial observers (Group 1) correctly identified more notes than unmusical observers (Group 3). The range of accuracy extended from perfec-

tion to one correct judgment out of 24 attempts. It was clearly seen, however, that a few of the unmusical observers equalled or bettered the performance of a few musical observers.

Comparison of the distribution of accuracy of all observers who judged piano notes with the distribution of accuracy for pure tones revealed a decrease in the level of performance. Examination of the percentages of correct pure-tone judgments shown in Fig. 3 indicates that musical observers (Group 2) were again more often right in their decisions than unmusical observers (Group 4). Although the range of accuracy for all observers extended from perfection to no correct judgements out of 22 attempts, compared with the

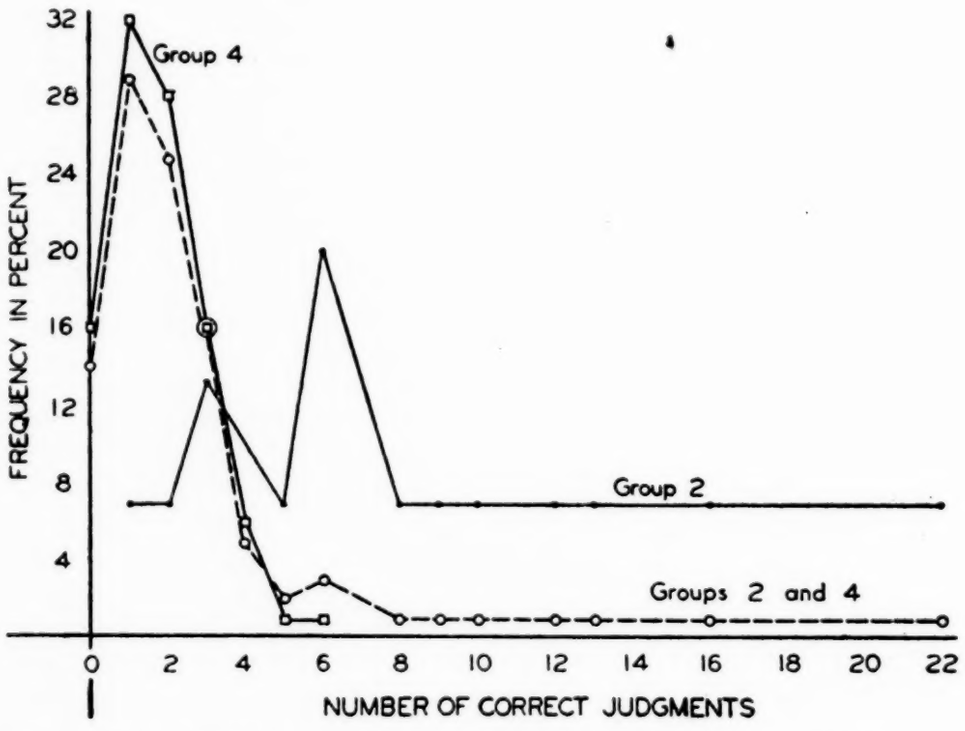

FIG. 3. The number of correct pure-tone judgments achieved by musical observers (Group 2) and unmusical observers (Group 4). Performance of both groups combined is shown by the broken curve.

distribution of accuracy for the piano note series shown in Fig. 2, greater overlap existed between the performance levels of the two groups. The reason for this greater overlap lay however, not in an improvement of the accuracy of unmusical observers, but in the inability of the musical observers to judge pure tones as accurately as they had judged piano notes. Fig. 4 illustrates the drop in accuracy of the musical observers. Only one observer maintained a perfect judging record, one observer identified correctly more pure tones than piano notes, and the remaining musical observers were unable to match the level of ability achieved when judging piano notes.

The results of the analysis of the number of correct judgments show that no sharp distinction can be drawn between the performances of observers who were originally selected to define the highest and lowest levels of pitch-judging ability. Greater accuracy was generally shown by the musical observers, however; an advantage that was considerably reduced when pure tones were substituted for piano notes.

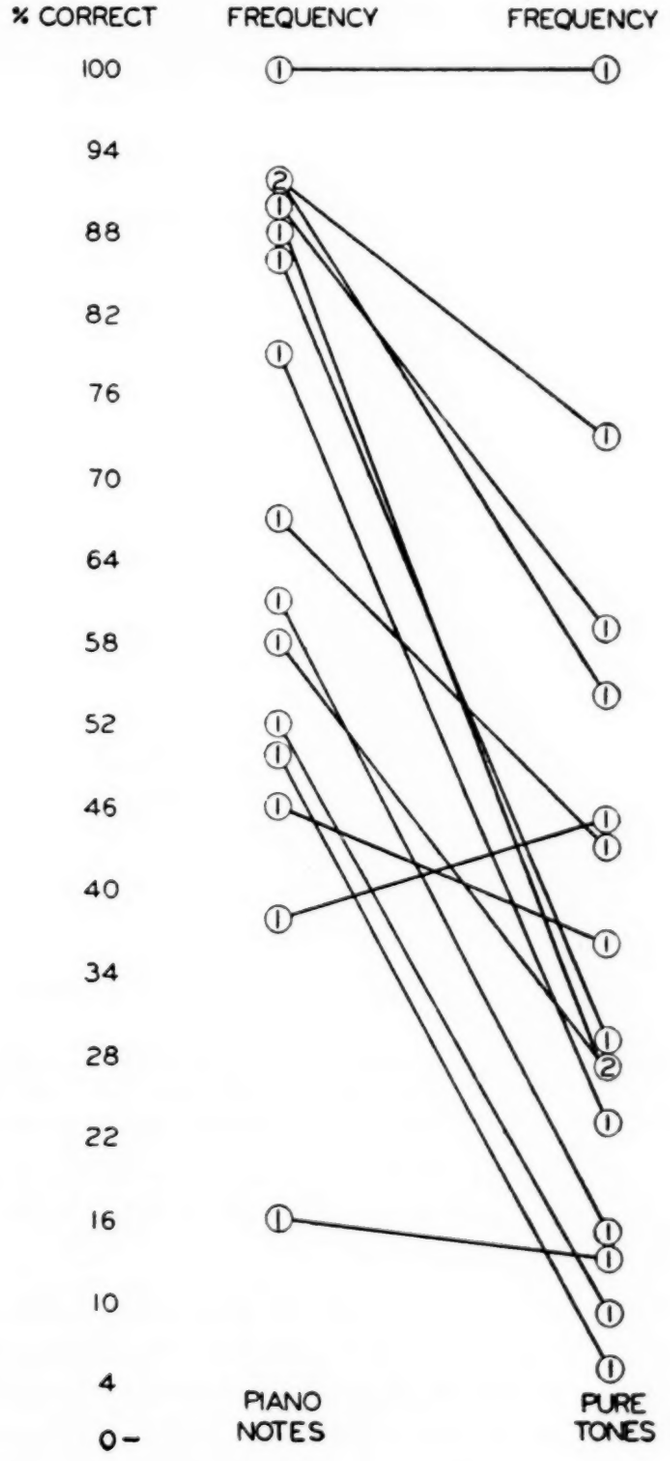

FIG. 4. Comparison between the percent of correct piano-note and percent of correct pure-tone judgments made by musical observers (Groups 1 and 2)

The conclusion drawn from these results is that musical observers who claim to possess a well developed sense of pitch give distributions of accuracy which are overlapped by those of unmusical observers. Decrease in the number of correct judgments when identifying pure tones is attributed to the loss of overtones, since the piano-note and pure-tone series were essentially the same, as were the groups of observers who were selected to judge each series of pitches. With these findings established, attention can now be given to the analysis of error made in judging the octave-interval of accurately named notes.

Octave–Interval Error Analysis

An analysis of the incidence of error in judging the octave interval is of particular interest because it has been contended that individuals who possess a well-developed sense of pitch are very likely to err in judging the tonal height of notes correctly identified as to note-name (Bachem, 1, 2).

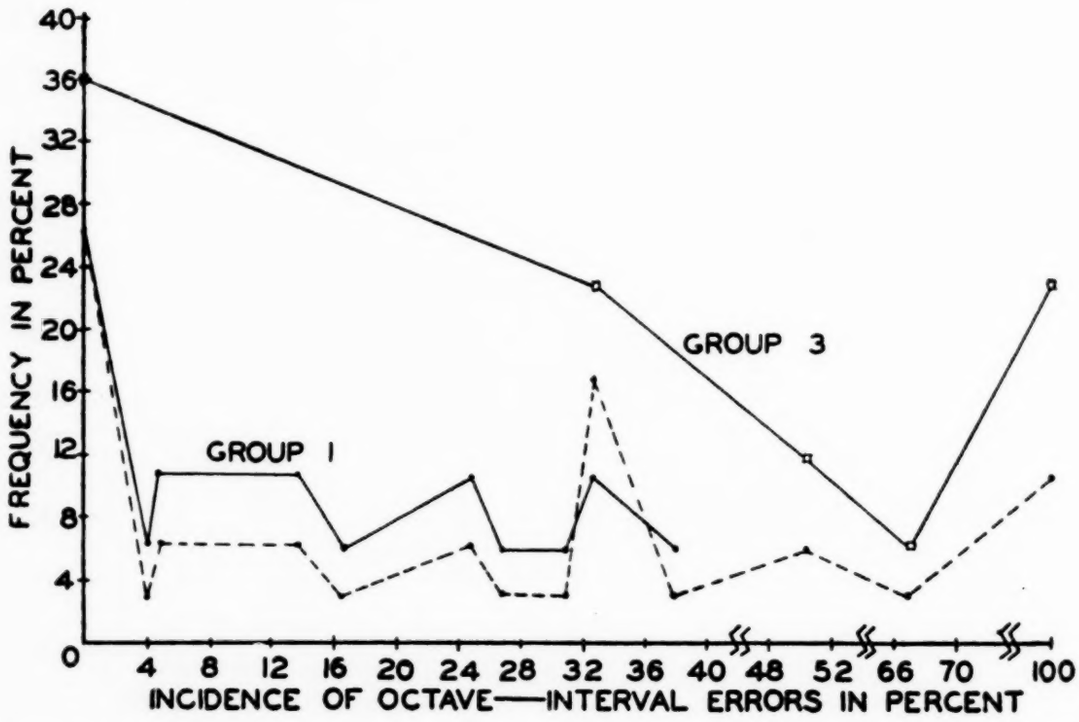

Fig. 5. Incidence of piano-note octave interval error in percent made by musical observers (Group 1) and unmusical observers (Group 3). Performance of both groups combined is shown by the broken curve.

Fig. 5 shows the incidence of octave error (the ratio of the number of incorrect octave-interval judgments to the total number of correctly named notes) made by the observers who judged the series of 24 piano notes. It is seen that musical observers (Group 1) generally proved *superior* to unmusical observers (Group 3) in judging the octave of accurately named notes. The range of octave error for the

musical observers ranged from no octave-interval errors (out of 22 correct judgements) to five octave errors (out of 13 correct judgments), with 94 percent of the musical observers having an incidence of octave-interval error of one-third or less. Unmusical observers ranged from no octave-interval errors (out of four correct judgments) to two octave errors (our of two correct judgments), with 59 percent of the unmusical observers having an octave-interval error incidence of one-third or less.

The results of this analysis clearly showed that the musical observers demonstrated greater ability than unmusical observers in judging the octave interval of piano notes, but in no sharply defined way.

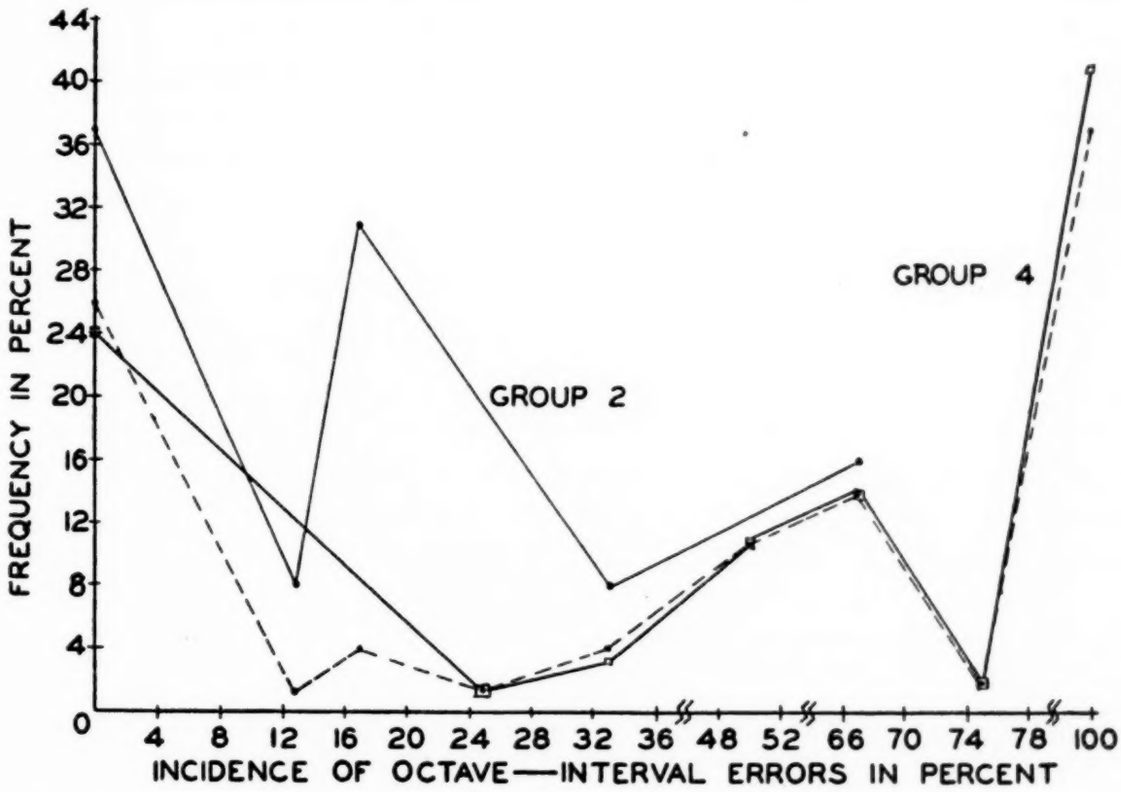

FIG. 6. Incidence of pure-tone octave interval error in percent made by musical observers (Group 2) and unmusical observers (Group 4). Performance of both groups combined is shown by the broken curve.

Comparison of pure-tone with piano-note octave error revealed that musical and unmusical observers made greater error in judging the octave-interval of pure tones. Fig. 6 shows the incidence of octave error for the series of 22 pure tones. Musical observers (Group 2) again were generally more capable than unmusical observers: their range of error extending from no octave errors (out of 22 correct judgments) to eight octave errors (out of 12 correct judgments), with 84 percent of the musical observers having an incidence of octave-interval error of one-third or less. Unmusical observers

(Group 4) ranged from no octave errors (out of two correct judgments) to six octave errors (out of six correct judgments), with 28 percent of this group having an octave-interval error incidence of one-third or less.

The results of the pure tone analysis reveal that, although unmusical observers were much less accurate judges of octave position of pure tones, their curve yields a distribution of octave-error incidence which overlaps that of the musical observers.

The conclusion drawn from these findings is that analysis of octave interval error reveals no basis for a contention that musical observers are likely to err greatly in judging the octave position of piano notes or pure tones. The group proved superior to unmusical observers in general, but lack of clear-cut distinction between the performance curves argues for continuity of ability. Pure tones reduced the ability of both groups to judge the tonal height of correctly named notes, a finding which suggests that overtone structure is a cue to octave determination. With these conclusions drawn, inspection can be directed to the analysis of incorrect judgments.

Analysis of Incorrect Judgments

An analysis of the extent to which incorrect judgments were misjudged is an important supplement to analysis of the number of correct judgments and octave interval errors, because analysis of the *degree* of inaccuracy may uncover a fundamental criterion upon which to base a claim of distinction between the judging performances of musical and unmusical observers.

Analysis of error revealed that musical observers came closer than unmusical observers to the correct identification of the series of piano notes and pure tones when inaccurate judgments were made. Musical observers showed a modal piano-note error of 2.5 semitones, compared with a modal error per note of 6.5 semitones made by unmusical observers. An unbroken distribution, however, marked the error performances of the two groups. The degree to which the series of piano notes were misjudged ranged from a mean error of 11.3 semitones to a mean error of .1 semitones.

A comparison of the distribution of piano-note error with the distribution of pure-tone error revealed that the amount of error increased in the latter. Musical observers showed a bimodal error of 3 and 6 semitones, while unmusical observers displayed a modal error of 9.5 semitones for the series of pure tones. The distributions of pure-tone error for the two groups ranged in an unbroken continuum from a mean error of 46.9 semitones to complete accuracy.

The conclusion drawn from these results is that error performance gives no clue to a basis for sharply defining the ability of musical

and unmusical observers. That pure tones effectively reduced the closeness of judgment compared with piano-tone judgments is attributed to loss of overtone structure. Since both groups of observers, when judging pure tones, decreased their number of correct judgments and also decreased their ability to judge the general location of tones that were misjudged compared with the levels of performance achieved when judging piano notes, the conclusion is drawn that physical overtones are secondary cues to pitch determination, and that loss of overtones is generally detrimental to pitch-judging performance.

Before turning to an analysis of the locus of most and least accurate judgments on the scale of pitch-frequencies it is important to consider the relative significance of the fact that musical observers as a group have demonstrated a consistent superiority over unmusical observers in ability to judge pitch. The conclusions so far drawn have not stressed this point, but have emphasized the finding of overlap between the performance distributions of the two groups. Reason for this one-sided emphasis can be found when the design of the experiment is considered. The musical observers, it will be remembered, were selected on the basis of claims of possessing a high degree of pitch-judging ability and, hypothetically at least, represented a small talented group taken from the musical population. It is significant, therefore, to find unmusical observers equalling or bettering the performance of these musical observers. The conclusion follows that the greatest significance derives from the finding that ability to judge pitch is not confined to certain highly trained or talented individuals, but distributes in a continuous fashion, even when experimental conditions were imposed which would clearly demonstrate the marked inferiority of an untalented and untrained group had it existed. With this consideration of the relative significance of findings concluded, attention can now be directed to the analysis of the locus of most and least accurate judgments.

Place Analysis

An analysis of the location of most and least accurate judgments relative to the placement of notes on the piano-keyboard range is a necessary addition to the analyses so far reviewed, because, as previously mentioned, apparently conflicting evidence has been reported. Petran (**6**) indicated that *musical observers*, judging *piano notes*, identified notes located in the middle region of the piano scale more accurately than notes at the extremes of the scale. Wedell (**7**), however, reported that *unmusical observers*, judging *pure tones*, identified tones less accurately in the middle region of a scale of pure tones compared with judgments of extreme tones.

Obviously the reported difference in locus of greatest accuracy may be based upon (1) differences between piano notes and pure tones as judging stimuli, (2) differences in the ability of musical and unmusical observers to judge pitch, or (3) both of these factors. The present study was designed to decide the issue by requiring musical and unmusical observers to judge piano notes and pure tones. If musical observers were more accurate when identifying pitch in the central regions of series of piano notes *and* pure tones compared to accuracy displayed at the extreme pitch-frequencies, it could be concluded that the difference between piano notes and pure tones as judging stimuli was not an operating factor. Similarly, if unmusical observers characteristically were *less* accurate when identifying pitch in the central region of series of piano notes and pure tones compared to accuracy displayed for the extreme frequencies, it could be concluded that the difference between piano notes and pure tones had no effect upon the characteristic tendency of this group. If these two conditions were met, the general conclusion could be drawn that the reported difference in locus of most and least accuracy was based, not upon stimulus differences, but upon a difference in the ability of musical and unmusical observers to judge tones that are variously located on a scale.

Comparisons of the degree of accuracy which were obtained for each pitch of the series of piano notes and pure tones are observable in Figs. 7 and 8. Examination of the distribution of piano-note error shown in Fig. 7 reveals that musical observers (Group 1) were generally more accurate in the middle region of the scale than they were at the extremes. Inspection of the distribution of pure-tone error shown in Fig. 8 indicates that musical observers (Group 2) were again more accurate in the middle region than at the extremes. Consideration of the performance of the unmusical observers (Groups 3 and 4), indicates that they were characteristically *less* accurate in the middle region of the scales than they were for extreme pitches.

Having asserted the opposing tendencies of the two groups on the basis of distribution inspection alone, it is important to consider at this point the possibility of further analysis. Since no absolute criterion exists upon which to base a decision as to what constitutes the 'middle region' and which pitches are to be considered 'extreme,' it is difficult to appraise in a wholly acceptable way the tendencies observable in the curvilinear distributions just noted. Statistical evaluation of the locus of most and least accuracy is given for the two groups of observers, but the arbitrary nature of the analysis should be kept in mind.

The four tones located at each end of the piano-note and pure-tone scales were designated as extreme, while the intervening tones con-

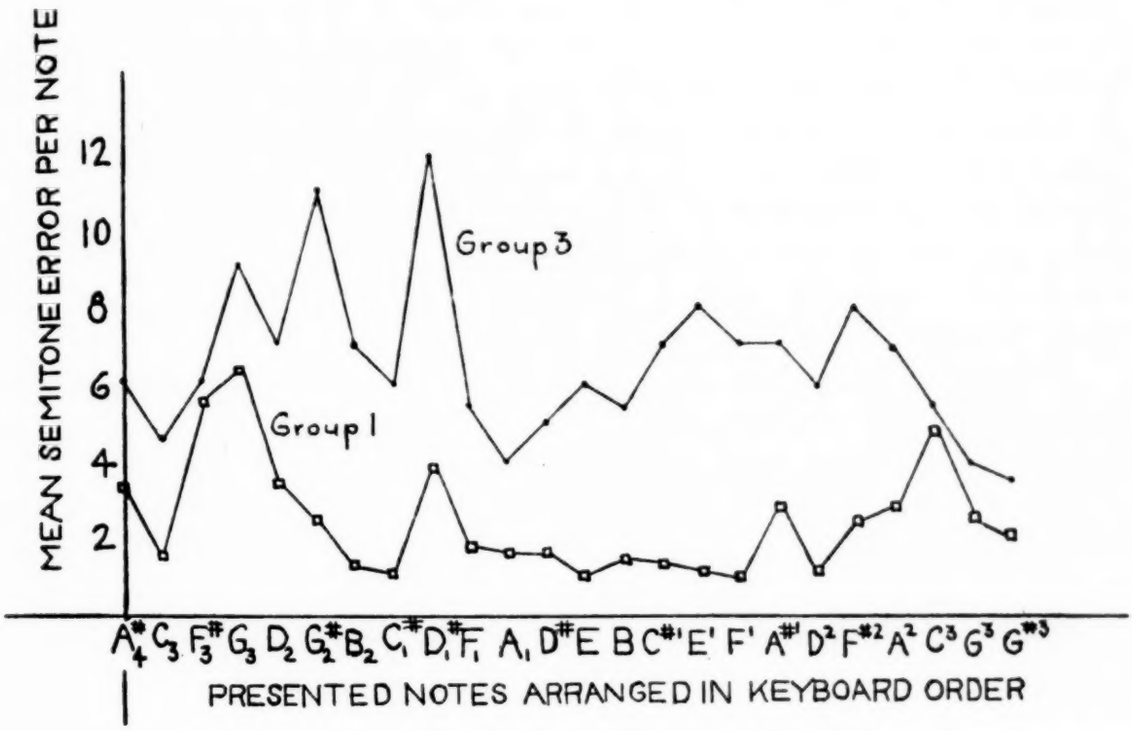
MEAN SEMITONE ERROR PER NOTE
12
10
8
6
4
2
Group 3
Group 1
A#4 C3 F#3 G3 D2 G#2 B2 C#1 D#1 F1 A1 D#E B C#1 E' F' A#1 D2 F#2 A2 C3 G3 G#3
PRESENTED NOTES ARRANGED IN KEYBOARD ORDER

FIG. 7. Average error per piano note made by musical observers (Group 1) and unmusical observers (Group 3).

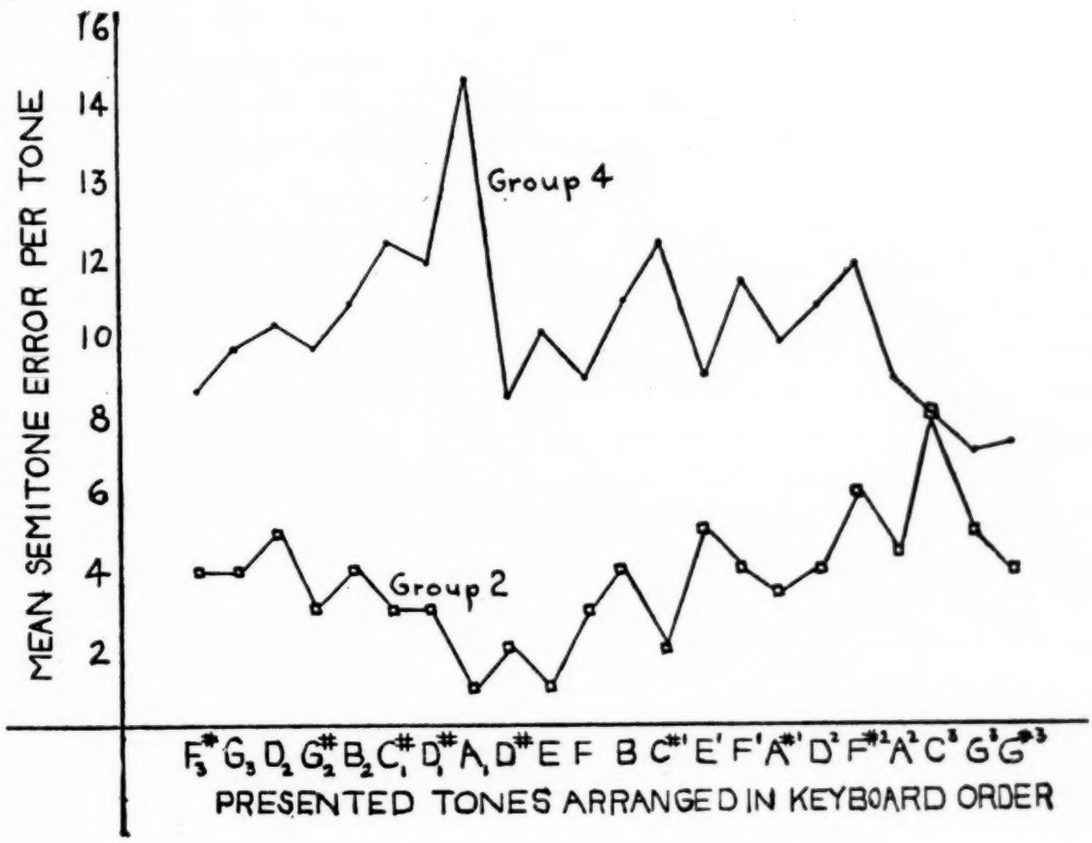

FIG. 8. Average error per pure tone made by musical observers (Group 2) and unmusical observers (Group 4).

stituted the middle region. A comparison of the average error made by the musical observers for the two tone groupings revealed that musical observers made a mean error of 1.9 semitones when judging 16 notes located in the middle of the series of 24 piano notes, compared with a mean error of 3.7 semitones for the remaining 8 notes located at the extremes of the scale. Their mean error for 14 pure tones located in the middle of the scale of 22 pure tones was 3.3 semitones, compared with a mean error of 4.2 semitones for 8 pure tones located at the extremes of the scale.

Unmusical observers made a mean error of 7.0 semitones when judging 16 notes located in the middle of the series of 24 notes, compared with a mean error of 5.8 semitones for the remaining 8 notes located at the extremes of the scale. Their mean error for 14 pure tones located in the middle of the scale of 22 pure tones was 11.0 semitones, compared with a mean error of 8.7 semitones for 8 pure tones located at the extremes of the scale.

Noteworthy is the consistent tendency of musical observers to be more accurate in the middle region of the piano-note and pure-tone scales and the tendency of unmusical observers to be less accurate in the middle region of the scales, compared with their accuracy for extreme pitches. Hence, the necessary conditions are met for the assertion that the locus of most and least accurate judgment does not vary as a function of the judging stimulus, but with differences in the ability of the observers. With this resolution of apparently conflicting reports concluded, consideration can be given to factors which could be present in the experimental situation to effect these opposed tendencies.

Such factors can be found. It will be remembered that the unmusical observers were liberal arts students who had little day-to-day, serious contact with music. The musical observers, on the other hand, had a great deal of daily experience with music, and as students of music were highly concerned with the structure of scales and the relationships of tones. Hence, it appears highly justifiable to consider how these factors could be operating. Wedell (**7**) offers a suggestion based on his investigation of the pitch judgments of unmusical observers. He found that his observers had greatest difficulty in identifying tones in the middle of the scale, and concluded that the judgments were made on the basis of a subjective scale that was carried within the observer (*cf.* Wever and Zener, **8**), with the ends of the scale serving as points of reference. The further away the note was located from these reference points, the more difficult was identification.

Applying similar reasoning in the present experiment, it follows that the most outstanding cues available to unmusical observers to

determine the pitch of piano notes and pure tones which cover the keyboard range are the upper and lower limits of the scale. As a result, their judgments of the pitch frequency of centrally located tones would be generally less accurate than their judgments of very high or low tones. The musical observers, however, presumably bring to bear day-to-day experience and practice with musical scores covering the middle region of the keyboard, which outweighs the factor of end points of reference as cues. Hence, their judging accuracy for extreme notes would be low compared to accuracy for tones located in the middle region. If musical observers, when judging extreme tones, do rely mainly upon a subjective scale with end points of reference, as do unmusical observers, then both groups would be using a common cue for judgment. Hence, the accuracy of judgment for the two groups should be fairly equal at the extremes of the scales. Figs. 7 and 8 show that musical and unmusical observers demonstrated a high degree of similarity in accuracy at the extremes of the scales, with an exception for low-pitched pure tones. In this connection, however, it will be remembered that the two lowest pitches of the piano-note series were omitted from the pure-tone series. Hence, the exception noted derived from a lack of evidence rather than contrary findings.

The inference drawn from the analysis of factors influencing the place of most and least accuracy is that musical and unmusical observers utilize end-points of reference to identify extreme tones, whereas accuracy in judging tones in the middle region of the scale, relative to accuracy for extreme tones, depends upon whether or not additional cues are available. Despite evidence given in Figs. 7 and 8 which indicated that the musical observers were more accurate judgers of pitch, inspection of the error distributions of the two groups for each tone in the series of piano notes and pure tones revealed considerable overlap between the curves, even for tones located in the middle region of the scale.

The general conclusion drawn from the results of the analyses of correct judgments, octave-interval error, amount of error, and locus of most and least accurate judgments is that pitch-judging ability is not confined to a specially-trained or talented group, but can be found to distribute in a continuous fashion, even when widely disparate groups constitute the total population viewed.

The generalizations which seem warranted in view of the total evidence are as follows: (1) that individuals having great experience with tone relationships are better able to judge pitch than non-musical observers, but in no discrete fashion; (2) musical observers are better able to judge pitch in the middle region of the piano scale—the region that is most commonly employed in musical score—than

they are at the extremes of the scale; (3) that the presence of overtone structure, also commonly found associated with tonal stimuli, effected a greater judging ability compared with judgments of pure tones; and (4) the musical observers who demonstrated nigh-perfect judging ability under the experimental requirements already considered possess a high order of learning and memory ability, as evidenced by inquiry regarding their scholarship records.

Generalizations (1), (2), and (3) lead to the hypothesis that ability to judge the pitch of a tone is a learned ability. Generalization (4) suggests two possible hypotheses: (1) that the musical observers who possess nigh-perfect judging ability have 'talent,' with the implication that they exercise an auditory perceptual ability which is different in *kind* from that possessed by most individuals; or (2) that these individuals as superior human specimens have developed, by reason of proper musical stimulation, a capacity to judge pitch into an ability at a level beyond that reached by average persons. This latter hypothesis is consistent with the hypothesis reached by consideration of generalizations (1), (2), and (3). The weight of the evidence appears to be in favor of the learning hypothesis. Hence, the general hypothesis obtains that ability to judge pitch is a learned ability.

Summary of Results and Conclusions

The aims of this investigation were to: (1) determine the range and limits of ability to judge a series of piano notes and pure tones, and (2) investigate factors associated with variability in accuracy of judgment.

From the evidence presented, the conclusion follows that no clear distinction can be drawn between the performance of musical observers, all of whom were selected on the basis of claims of pitch-judging ability, and the performance of unmusical observers, none of whom claimed ability to judge pitch.

This evidence has been gained by means of four analytical approaches to the problem: first, through an analysis of the distribution of correct judgments; secondly, through an analysis of octave-interval error; thirdly, through an analysis of the amount of error; and fourthly, through analysis of the place on the scale of most and least accurate judgments.

The results obtained from the analysis of correct judgments indicated that accuracy in judging piano notes and pure tones ranged from perfection to no correct judgments. The musical observers in general showed greater ability than unmusical observers. It was significantly noted, however, that despite the great difference in *claimed* ability of the two groups, an unbroken distribution of pitch

judging ability obtained for the piano and pure tone series. Correct identification of piano notes occurred more frequently than correct identification of pure tones, indicating that loss of the physical overtone structure is detrimental to pitch judging ability.

The results of the octave-interval error analysis indicated that musical were generally superior to unmusical observers in ability to judge the octave position of correctly named notes, but that all evidence indicated a continuous distribution of performance from perfection to no ability. Overtone loss increased the incidence of octave error in both groups, suggesting that judgments of the tonal height of correctly named notes are favorably influenced by the presence of physical overtones.

The results of the analysis of degree of inaccuracy of incorrect judgments demonstrated that the amount of error ranged from complete accuracy to a mean error of 46.9 semitones for the entire series of tones. Musical observers, when incorrectly identifying tones, did not err as much as unmusical observers. But again, no line of demarcation characterized the apparently contrasted groups. Erroneous pure-tone judgments were less accurate than erroneous piano-note judgments, a finding which held for both groups and supported the view that over-tones are not only cues to the determination of the note-name and the correct octave, but also aid in judging the general location of notes that were incorrectly identified.

With these facts established, an analysis of the place on the scale of most and least accurate judgments of pitch demonstrated that musical observers, when judging piano notes *and* pure tones, characteristically made less error in the middle region of the scale than at the extremes. Unmusical observers, while their accuracy for extreme tones compared favorably with the accuracy of musical observers at the extremes, made greater error in judging tones in the middle region of the scale than at the extremes. The similarity of the two groups at the extremes was attributed to the utilization by both groups of the ends of the scale as points of reference. Since the locus of most and least accurate judgments did not vary as a function of the judging stimuli employed, it is concluded that musical observers characteristically increased their accuracy in identifying tones of the middle region compared with their accuracy for extreme tones, and that unmusical observers characteristically showed an opposed tendency, a finding that resolved apparently conflicting evidence regarding the locus of least and most accurate judgments. The reason for this characteristic difference between musical and unmusical observers is inferred to lie in the fact that musical observers employ cues gained in day-to-day experience with music which outweigh the end points of the scales as bases for judgment, whereas

unmusical observers do not have the opportunity to gain additional cues and must rely solely upon the scale limits. Since end points of reference are the least effective cues for centrally located tones, unmusical observers are least accurate in this region.

Despite the opposed tendencies just noted, inspection of the individual distributions of error for each of the tones employed in the series revealed that considerable overlap in the error curves of musical and unmusical observers existed, irrespective of the location of the tone in series.

The conclusion is drawn, therefore, that ability to judge pitch distributes continuously throughout apparently contrasting groups, with performances ranging from perfection to little or no ability. This conclusion controverts the assumption that ability to judge pitch is confined to specially trained or talented individuals. The presence or absence of overtones contributed to variability in level and degree of accuracy, while variability in place of most and least accuracy was inferred to be a function of the extent of day-to-day experience with music.

Generalizations based on considerations of the total evidence favored a learning hypothesis. Hence, the general hypothesis obtained that ability to judge pitch presented by the method of single stimulus is a learned ability. The findings in the present study make possible a more complete account of individual differences in ability to judge pitch than hitherto has appeared and should function to dispel the common belief that pitch-judging ability is a special achievement of the few.

(Manuscript received October 24, 1945)

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THE RATE OF LEARNING MEASURED AT A SINGLE SYNAPSE[1]

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I. Introduction

Learning curves previously presented in the literature have been graphic descriptions of observable changes in the performance of subjects or physiological preparations trained according to the conditioning or learning procedures accepted by physiologists and psychologists. Learning has regularly been thought of in terms of modification of performance, with the assumption that the cells of the central nervous system in some mysterious way acted in an integrating manner to vary behavior in accordance with 'the learning curve,' which was found under different conditions to be sigmoid, negatively accelerated, positively accelerated, and in a few instances a straight line. The literature is full of these so-called learning curves which are based on the modification of external performance and should be called learned-performance curves. They are a by-product of the assumed internal or central learning.

A *true learning curve* should be a representation of the rate at which learning progresses within the central nervous system from its inception to completion (the limit set by the criterion), not a record of the external learned responses dependent upon this central learning process. The curve derived in this paper is the basic curve of learning for a single element of the central nervous system as it learns to initiate a modified response in a muscle.[2]

Some years ago we compiled a mass of data on a phenomenon which we designated the 'spinal conditioned response' or 'spinal CR.' The original composite curve of spinal conditioning (**1** and **2**) was negatively accelerated and showed the relationship between percentage of trials and percentage of learned responses. Fifty percent of

[1] Publication No. 3 in a series of experiments on 'Neural and Physiological Bases of Learning,' the greater portion of which were completed during tenure (1939–40) of a National Research Council Fellowship at the University of Rochester. For publications Nos. 1 and 2, see (3) and (5).

[2] A paper is being prepared discussing the relation of single synaptic learning to its initiated modified response and the learned-performance curve.

the conditioning was shown to occur in the first forty percent of teh trials.

The curve which we present here, while derived from external performance or spinal conditioned behavior, is actually a measure of the rate of internal learning. Specifically, this learning curve represents the *modification of a single learning nerve cell's ability to respond.* It is a measure of internal learning (i.e., the rate of a single cell's cumulation of ability to respond, from zero responses to the maximum of responses set by the criterion) and it differs markedly from external performance curves from which it is derived.

I. Technique

This paper deals with spinal learning data from isolated segments of the lumbar-sacral spinal cord of dogs. Detailed operational procedures (both surgical and test techniques) were described at length in earlier papers (1, 2, 3 and 5).

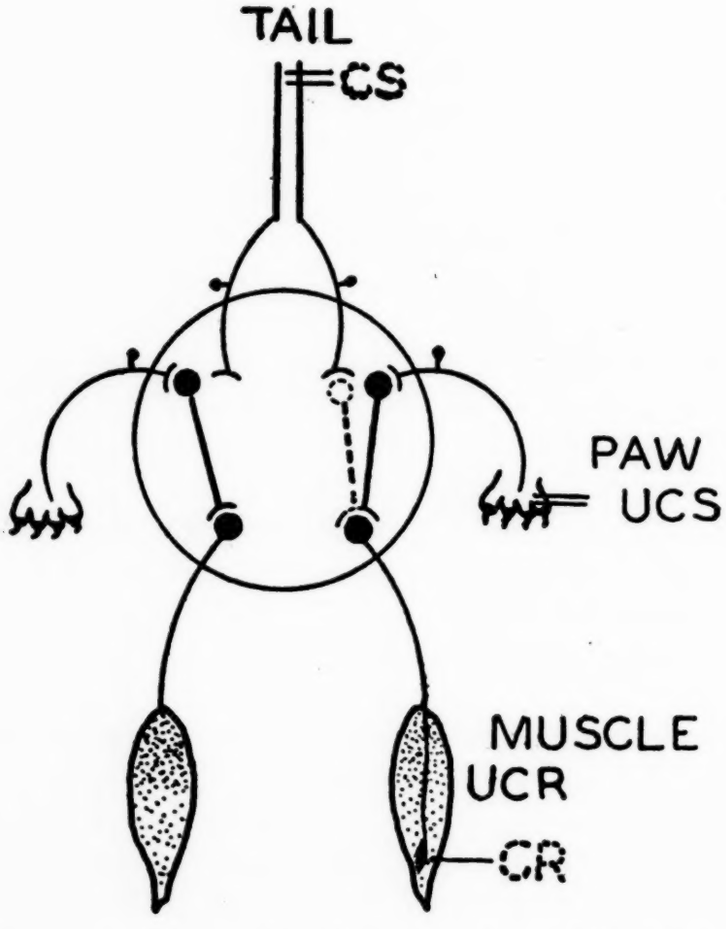

Fig. 1. A diagramatic representation of a cross-section of the isolated spinal cord showing the basic neural aspects of localization of the central learning function. CS is a slight stimulation of the tip of the tail; UCS is a stimulation of the paw which produces the UCR, a complete contraction of the whole muscle; CR is a response of a none-or-all muscle fiber unit which is innervated by a single motor neurone. The dotted neurone represents the complex operational processes of learning which result in the growth of a learned response of the individual motoneurone as it learns to initiate its nerve impulse in response to a specific sensory conditioned stimulus.

The spinal cord was severed at the level of the third lumbar spinal root. The essential blood supply remained intact. Both semitendinosus muscles were exposed, carefully excised; their insertional ends were observed through binocular microscopes or attached to recording devices. The learned response or CR occurs only in the semitendinosus muscle of the trained leg. In these experiments the contralateral or untrained muscle was never observed to respond to the conditioned stimulus (CS).

Electrodes were attached to the tip of the tail and to one hind foot (Fig. 1). Two very weak shocks were applied to the tip of the tail (CS), the second accompanied by the unconditioned stimulus (UCS), a shock to the paw strong enough to elicit a full contraction of the whole semitendinosus muscle. When the learned response of the originally responding motor unit reached 100 percent (i.e., when it responded to every CS in a unit of 10 trials; each succeeding 10 trials was regarded as a unit of training and perfect response was not necessarily attained by responding correctly 10 times in succession), the process of extinction was begun. This consisted of repeated trials in which shocks to the tail were applied at the training intervals without the reinforcing UCS shock to the paw. Extinction was continued until the muscle failed to respond throughout a unit of 10 trials.

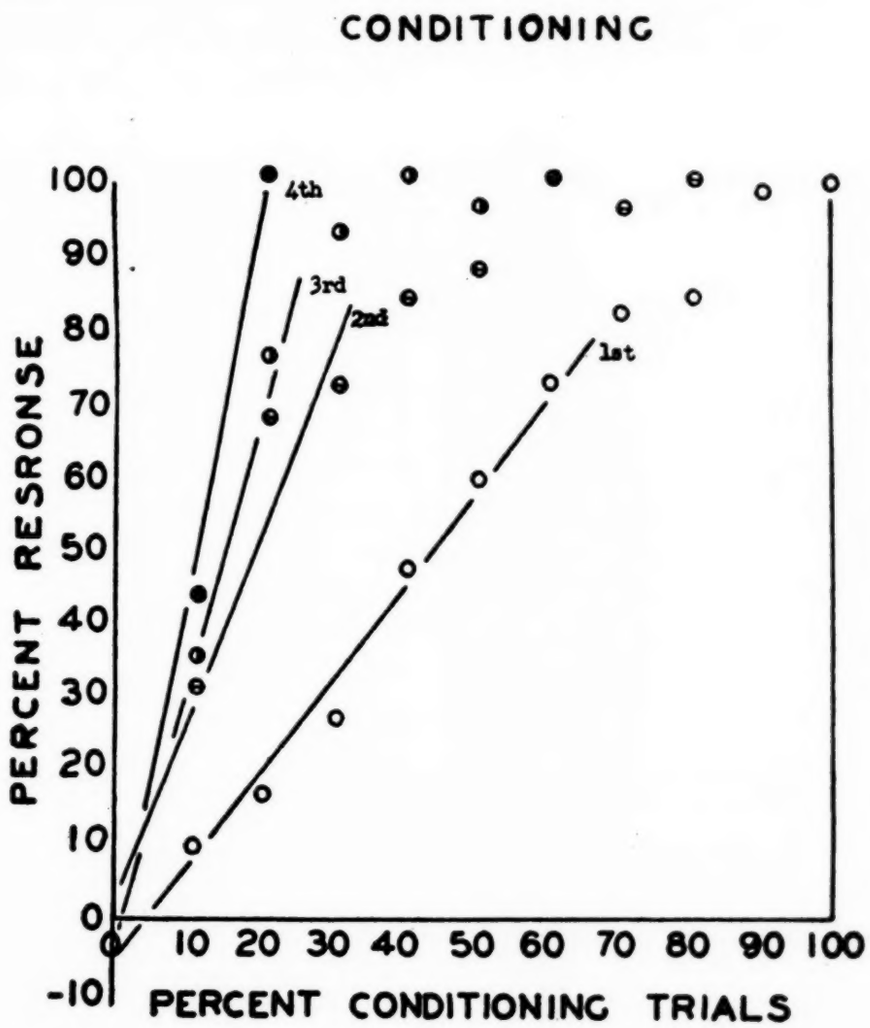

FIG. 2. Ordinate: PERCENT RESPONSE represents the average percent of the learned response of a none-or-all muscle fiber group innervated by a single motoneurone in isolated spinal cords of dogs. Abscissa: PERCENT CONDITIONING TRIALS represents the percentage of trials required to attain the criterion of 10 responses in a tens unit. Open circles, 1st conditioning or learning; circles with horizontal bar, 2nd conditioning or 1st reconditioning; half black circles, 3rd conditioning or 2nd reconditioning; and black circles, 4th conditioning or 3rd reconditioning. Circles are not inscribed after 100 percent performance (response) is attained and maintained to the criterion. The four straight lines fitted through zero represent the velocities of the four successive conditioning series.

The conditioning-extinction-first reconditioning-first reextinction-etc. technique (1 and 2) was utilized in this experiment. Each dog was trained through the third reconditioning-third reextinction (fourth conditioning-fourth extinction). Vincent curves are plotted from the data.

The derivation of the internal learning curve for a single motor neurone is based upon the first derivative, or velocity, of each succeeding conditioning (Fig. 2). The *dc/dt* slopes were derived by fitting straight lines by the method of least squares. The part of each conditioning curve through which the straight line was fitted was selected by inspection. The points in each negatively accelerated curve after that point at which the slope of the curve altered sharply were eliminated. The *dc/dt* slopes plotted against the four repetitions of conditioning (Fig. 4) yield a curve which is the velocity of their velocities or the *internal acceleration curve of cumulating ability to respond*. This curve represents the rate of learning measured at the single synapse.

III. Results

The CR first appears as the contraction of a small group of muscle cells or fibers in the insertional pit of the semitendinosus muscle (see Fig. 3, and [1]). This group of muscle fibers (less than 200) responds as a none-or-all unit. Frequently this first none-or-all

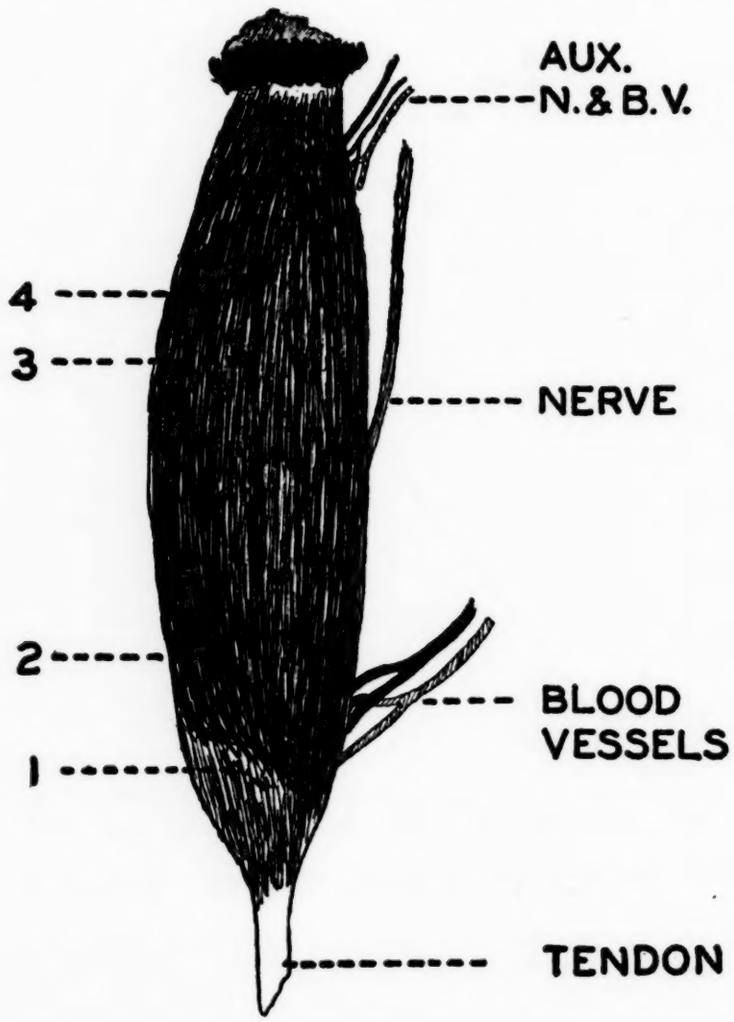

Fig. 3. A diagramatic representation of the semitendinosus muscle, showing the location at which the learned response is first observed (1) and the areas (2, 3 and 4) of the muscle progressively included in the response; Aux N. & B. V., the auxilliary innervation and blood supply of the origin; the main nerve and blood vessels are found respectively nearer the belly and the insertional end of the muscle.

muscle fiber unit can be conditioned and extinguished before a second unit begins to respond.

As conditioning trials are continued, more and more muscle units may become conditioned, as is shown by the participation of additional none-or-all muscle fiber units in the contraction. The learned response may progressively include other motor units from the insertional pit toward the origin of the semitendinosus muscle (Fig. 3, 1, 2, 3, and 4). So far as we could tell, there was never an exception to the rule that when any learned response occurred, the first none-or-all muscle fiber unit to be conditioned contracted. This most superior none-or-all motor unit was found to learn more rapidly in each succeeding period of reconditioning (Fig. 2). Extinction also occurred more rapidly as the experiment progressed.

Dogs not alternated through the required four repetitions of the conditioning and extinction processes show the same pattern of more rapid success in both conditioning and extinction as far as their training was continued. Still other test animals were alternated many more than four times and in many cases training reached the limit set by the criterion (i.e., reconditioning was accomplished in a single trial and persisted through the succeeding 19 conditioning trails). Four of the five preparations in this experiment reached this limit.

Even when extinction of the CR in the none-or-all unit was complete and no observable response to the CS could be elicited, a residue of learning (memory) remained and was demonstrated by the increasing speed with which the CR could be reestablished (Fig. 3). Since this residue was cumulative, it was measureable: by (1) determining the dc/dt slopes (velocities) of the response curves in each successive period of learning (Fig. 2), and (2) plotting each slope (dc/dt) of the successive performance curves against its repetition of the learning or conditioning process (Fig. 4), the rate (acceleration) of learning in the isolated segment of spinal cord was established. The curve derived in this way we call the internal, the central, or the true learning curve of a single motor synapse of the none-or-all muscle fiber unit in distinction from the observable learned muscle-response curves of the none-or-all muscle fiber unit.

Fig. 4 is compiled from data obtained from five spinal dogs. The learned response curves used in the computations were average curves. We secured from each of the animals a series of four conditioning curves, representing the learned responses of the single motor unit which learned most rapidly in each of the semitendinosus muscles observed during successive periods of conditioning. We then plotted an average learned performance curve for conditioning, and average curves for the first, second and third reconditioning (Fig. 2). When the slope of each average learned performance curve is plotted against

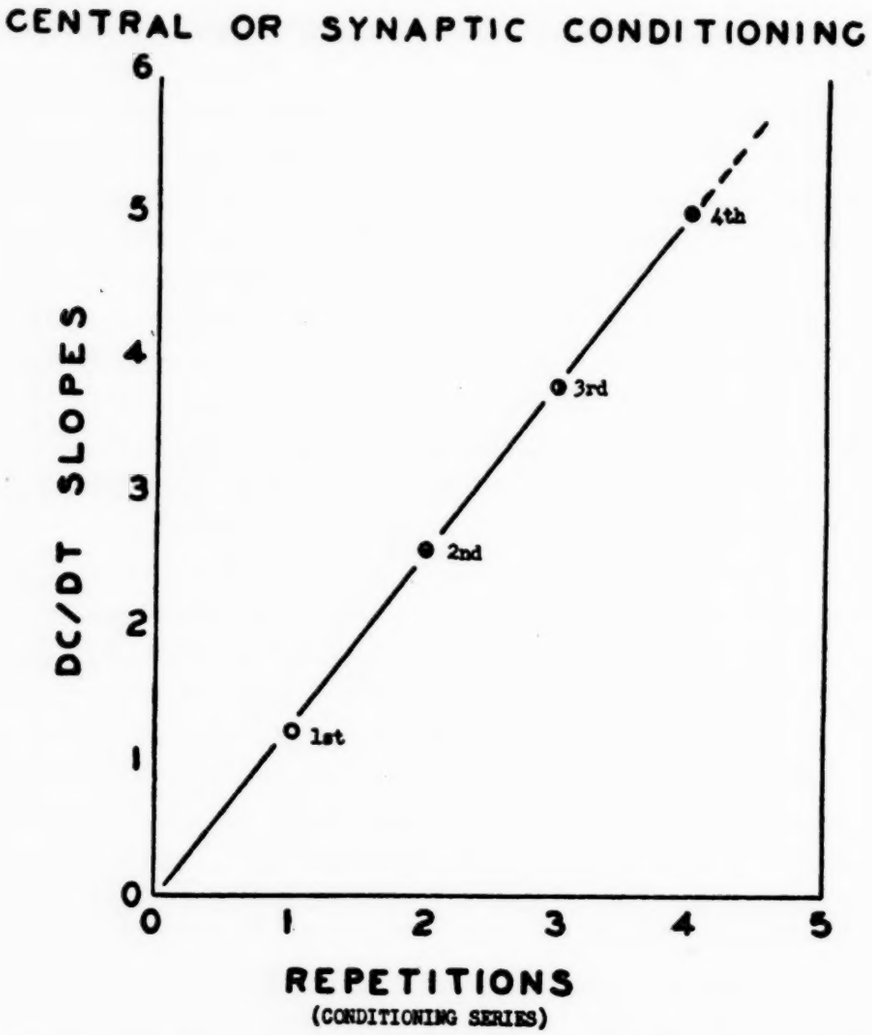

FIG. 4. Ordinate: *dc/dt* SLOPES represent the velocities of the four successive conditionings or learnings of a single motoneurone in the average isolated spinal cord of the animals used. Abscissa: REPETITIONS represent the successive conditionings presented in Fig. 2. This curve is fitted by the method of least squares and has a slope of 1.2 and an intercept at − 0.2.

its conditioning, a curve results (by the method of least squares) which is a straight line proceeding from zero with an intercept at −0.2 and a slope of 1.2. This straight line represents the rate or accelleration of the central learning of the most conditionable single motor cell which effected the learned responses of the none-or-all muscle fiber unit in the average semitendinosus muscle as its ability to respond proceeds from zero to 100 percent performance determined by the limit set by the criterion.

IV. Discussion

When the first overt learned response occured in the semitendinosus muscle it was the none-or-all contraction of a small group of muscle cells or fibers. This irreduciable muscle fiber unit must be innervated by a single motor neurone. It therefore seems definite that *the motor neurone synapse is the specific location of the spinal*

learning function, for the following reason: the sensory impulses at the axonic 'boutons' of the internuncial neurones impinge upon dendrites and cell bodies of many motor neurones in the motor neurone pool of the central nervous system. If the learning took place at the sensory or internuncial dendritic and cell body synapses, or both, the axonic impulses of an internuncial would impinge upon many motor neurones and include many motor units in the initial learned response. The motor neurone, once adequately stimulated, propagates an impulse which will activate its none-or-all muscle fiber unit unless an active step in the propagation of the impulse or an active step in the myoneural junction is blocked. Since the first learned response is the contraction of an irreducible number of muscle fibers actually so specifically limited as to be innervated by a single motor neurone, it follows that learning must occur in that particular motor cell or its synapses, or both.

The average learned spinal performance curves presented above are based upon minimal learned motor responses, and represent the average curves of learned performance for the *most superior cell* of the group of cells innervating the semitendinosus muscles of the young mongrel dogs used. From these four learned response curves we derive the curve of the rate of learning for the single motor nerve cell which innervates this minimal learned or conditioned response.

Much of the literature still implies that mass functional action of central nervous system tissue must be called upon to explain the learned recovery of ability to perform previously learned acts lost due to injury. We have demonstrated that individual cells learn independently at the spinal level and we believe that this same principle of learning must apply at cortical levels on the analogues of the motor neurones. The authors are preparing a paper in which thirty-five acute and chronic preparations are used to demonstrate this point-for-point learning in Brodman's Area 4.[3]

V. Summary

1. Learned extrinsic performance is demonstrated in the spinal dog in its simplest form, a muscle fiber group innervated by a single motor neurone.

2. A method is described for measuring the rate of true learning within the central nervous system for the basic muscle response unit.

3. Measured extrinsic learned performance of the most superior learning motor unit in the spinal dog is used to measure the rate of central, synaptic, or true learning of a single motor neurone.

[3] The original study was entitled *Specific functions ascribed to the agranular motor cortices, corpus callosum, and contralateral and ipsilateral pyramidal tracts in conditioning and extinction*, and was presented at the 1941 APA Meeting, along with slides and the motion picture, *Transferred and substitute conditioned responses.*

4. The central learning curve or rate of cumulation of ability to respond for a single motor neurone in the isolated spinal cord of the dog is shown to be a straight line.

5. Central nerve cells (motor neurones) demonstrate independent ability to learn.

(Manuscript received November 14, 1945)

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LEVEL OF AUTONOMIC ACTIVITY AND ELECTROENCEPHALOGRAM*

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The level of autonomic activity as well as the magnitude of response to stimulation must be taken into consideration in evaluating autonomic effects on the electroencephalogram. Reaction to stimulation involving an altered 'level of excitation' has repeatedly been studied both as 'blocking effect' on the EEG (**1, 4, 5, 6, 58, 59, 84, 85**) and as blocking with concomitant autonomic reactions (**6, 23, 28, 36, 39, 48, 63, 64**), such as changes in heart rate (HR) or as the galvanic skin response (GSR). Identity of blocking conditions (**1, 5**) for the EEG with the 'intention,' 'attention,' 'alertness,' and apprehension which are recognized (**15, 84, 85**) as precipitating conditions for the GSR has been noted by Jasper (**53**). When protracted into a chronic state these conditions have been identified psychologically and psychiatrically as 'tension' or 'anxiety' and have been found often associated with low potential fast activity in the EEG (**9, 24, 45, 56, 62, 80**) and with low palmar resistance (high conductance, sweating) in the GSR (**16, 29**), and both have been associated with increased temperature or metabolism (**41, 50, 51, 54, 63**). Such persisting states or levels of excitation have been referred to neurophysiologically as 'the central excitatory state' or as 'excitation background' (**17, 52, 53**).

Because EEG potentials are reduced as cerebral activity is increased the correlations with bodily changes under conditions of excitation tend to be negative. The relation of EEG to levels of physiological function in the absence of central excitation, on the other hand, has been less frequently studied. Of particular interest is Hadley's (**47**) finding among a group of individuals of a positive correlation of $r = .33$ between levels of resting heart rate and occipital EEG potential. This is the opposite relation to that where heart

* Preliminary report: *Fed. Proc. Amer. Soc. exp. Biol.*, 1945, 4, 16.

rate is increased and EEG amplitude is decreased (or frequency increased) by excitation (**24, 48**). A relation similar to Hadley's (**47**) appears in the present study. The possibility that this relationship characteristic of the resting state is attributable to a predominance of subcortically determined regulatory activity over central excitatory (cortical?) effects on the EEG (**20**) is in harmony with generally accepted views regarding the mechanism controlling the alpha potential.

It has been frequently explained that the presence of a strong alpha potential in the resting waking state is due to the rhythmic activity of large numbers of neuronal elements driven in synchrony (**1, 20, 41, 44, 50, 59**) by the thalamo-cortico-thalamic resonating circuits described by Bishop and Dusser de Barenne and McCulloch (**7, 8, 31, 33**) or by a frequency generator in the thalamus as inferred by Morison *et al.* (**68, 69**). Stimulation and increased central excitation, it has been pointed out, result in brain elements breaking synchronization and taking up their own individual rates of discharge. Large voltage potential differences are thereby cancelled out and overall recorded frequency is increased. As with soldiers crossing a bridge, the breaking of step prevents oscillation. By this explanation negative correlations of EEG with cortically dominated activity during central excitation and positive correlations with subcortically determined activity in the absence of central excitation would be accounted for.

Method.—Electroencephalograms of 120 persons with systolic blood pressure above 110 mm. Hg, on whom we had relatively complete autonomic and EEG records of changes during overbreathing,[1] were measured and important data punched into cards for analysis. Methods of recording EEG, galvanic skin reflex, systolic blood pressure, relative blood pressure, heart rate, and respiration have been described elsewhere (**23, 26**).

The EEG was recorded from 8 to 10 scalp and 2 connected ear lobe electrodes. The present study concerns the analysis of measurements of bipolar records between left parietal and left occipital leads. The measurements are of predominant, repetitive, relatively sinusoidal activity above 6 per sec. A representative segment of record preceding hyperventilation was selected by inspection from the record of each *S* and this was measured for voltage and frequency. A simultaneous electrical record of eye movement permitted elimination of artifacts due to blinking, opening the eyes, and rotation of the eyeballs (**49, 65, 82**).

Systolic blood pressure was recorded from the ankles with the *S* in a reclining position. A continuous sphygmomanometric record of blood pressure was obtained from the other ankle, comparison of the two records permitting elimination of artifacts attributable to movement. Respiration was recorded by a pneumograph on the chest.

The galvanic skin reflex (GSR) was recorded between an active electrode on the right palm and an indifferent electrode on the back of the wrist, resistance of the latter being largely eliminated by rubbing with electrode paste. Palmar skin conductance in micromhos (reciprocal ohms $\times 10^6$) during the resting control period before overbreathing was used as an index of palmar sweating. Palmar sweat reaction to stimulation is neurologically a sympathetic function, mediated peripherally by acetylcholine (**18, 19, 60**) and centrally controlled from forebrain areas

[1] Referred to as 'hyperventilation.' *S*s breathed deeply at about 15 inspirations per min. for periods of one min. After rest the procedure was several times repeated with each *S*. The data reported here were obtained prior to overbreathing.

concerned with manipulation and grasping (18).[2] Levine and Wolff (61) have shown that it may be affected also by reflexes from the cerebral blood vessels.

Heart rate was determined by an EKG of low amplification from electrodes beneath the armpits. Rate per min. was determined from the number of inter-R intervals and fractions thereof × 10, during six sec. (26). Heart rate is known to be determined by both sympathetic and parasympathetic influences. Parasympathetic regulation of the heart via the vagus is recognized as the more important. Relation of EEG to increased heart rate during hyperventilation (2, 3, 25, 26) especially when possible sympathetic influences can be eliminated, indicates the effect on the cortex of a decrease of parasympathetic cholinergic activity.

Results—Product-moment correlations determined between EEG and autonomic measures are presented in Table I. Negative cor-

TABLE I

CORRELATIONS, r, OF PARIETAL-OCCIPITAL EEG WITH AUTONOMIC ACTIVITY

	Conductance	Initial Heart Rate	Initial H.R. + Conductance / 2
P-O Frequency ($N=120$).....	−.20	−.21	−.21
P-O Potential (all frequencies, $N=120$)	.28	.33	.48
P-O Potential (9–11 frequency, $N=76$)..	.38	.30	.43
P-O Potential (age 15–20, all frequencies, $N=45$).....	.40	.30	.47

Systolic blood pressure over 110 in all cases.

relations, $r = -.21 \pm .06$, between EEG frequency and resting skin conductance, and $r = -.21 \pm .06$, between EEG frequency and resting heart rate are of interest in that they rule out possibility that these effects are due to individual differences in temperature or metabolic level. EEG frequency and skin conductance (sweating) as previously noted, and likewise heart rate are increased by elevation of temperature or metabolism and in the presence of such changes are *positively* correlated with one another (54, 63, 76, 77). Negative correlations[3] among these measures when they are obtained from persons in the resting state indicate that factors other than variations of temperature or metabolic level are probably operative.

The correlation $r = .28 \pm .06$ between parietal-occipital EEG

[2] Simultaneous records of both monopolar (to ear lobes) and bipolar (intercortical?) EEG's from various areas now made possible by 12-channel equipment have shown palmar galvanic response to nonvisual stimuli to be typically associated during the latent period preceding galvanic reaction, with low potential fast activity in bipolar frontal-motor leads. Low potential fast cortical activity discharging into precentral cortical sympathetic centers may thus be related to the galvanic response to stimulation.

[3] Negative correlations with EEG *frequency* are consistent with the positive correlations with EEG *potential* which follow, for EEG potential tends to very inversely with frequency (44, 57).

potential and resting palmar skin conductance, though low, is important. It shows that notwithstanding all the other factors contributing to EEG in a random sampling of individuals, sympathetic activity nevertheless has appreciable relationship to it and a possible influence. Simplification of relationships by elimination of frequencies above and below the adult range of 9 to 11 per sec. appreciably increased the correlation to $r = 38 \pm .07$. Simplification by elimination of cases of ages other than between 15 to 20 years of age gave a correlation of $r = .40 \pm .08$.

EEG potential relates to heart rate, $r = .33 \pm .06$, for all cases, with nothing gained by elimination of frequencies above and below 9 to 11 per sec. or by narrowing age range to 15 to 20 years. This, it is to be noted, is the identical figure reported for this correlation by Hadley (**47**). There is no positive correlation between blood pressure and EEG potential, $r = -.14 \pm .06$, thus eliminating the possibility that results are attributable to blood supply.[4]

These correlations indicate that in the resting state sympathetic activity and inhibition of parasympathetic activity are associated with increase of alpha potential. This suggests possibility of synergistic action. Combination of properly weighted values for skin conductance and heart rate should give in that case increased correlation with EEG potential.

Combination of scores according to an empirically determined weighting,[5] *heart rate* + *conductance*/2, gave the correlation $r = .48 \pm .05$ with EEG potential. The distribution of scores on *heart rate* + *conductance*/2 plotted against EEG potential is presented in Fig. 1. Tracings of EEG from a person in each cell of the distribution illustrate the relationship. The correlation suggests possible synergistic action on EEG of sympathetic tone combined with inhibition of parasympathetic tone. Such a synergistic effect is understandable when it is recalled that sympathetic activity and inhibition of parasympathetic activity both increase tone in the cerebral blood vessels (**12, 13, 14, 37, 75, 78, 79**) and that increased tone in the cerebral blood vessels tends to accompany increased EEG potential (**2, 3, 21, 22, 23, 25**). Decreased cholinergic facilitation of

[4] Homeostatic effects of blood pressure (and blood flow) on EEG (**23, 25, 27**) and on autonomic function (**40**) have been previously reported.

[5] To determine optimum weighting for such a combination, conductance was plotted against heart rate with values for EEG potential written into the graph. The slope of the line giving best separations of higher from lower EEG potential scores was *heart rate* + *conductance*/2 = *constant*. This indicated the relative weighting of the scores offering the best possible correlation of the combined scores with EEG.

This combination of scores on conductance with those for heart rate is justified if the two measures are independent and heart rate is uncorrelated with skin conductance. Correlation of conductance with heart rate was $r = .07$.

neuronal transmission with reduction of fast and sharp waves doubtless contributes to the effect (**22**).

Discussion—Correlation coefficients of the magnitude here reported are admittedly not impressive in a psychological field where usefulness is gauged by *predictive value*, and correlations under $r = .80$ are accordingly worth little consideration. The significance of these correlations, however, lies not in their predictive value but in the evidence offered for a relationship where no relationship has been recognized before, and in thereby offering evidence for a missing factor among those known to control the waking resting electroencephalogram.

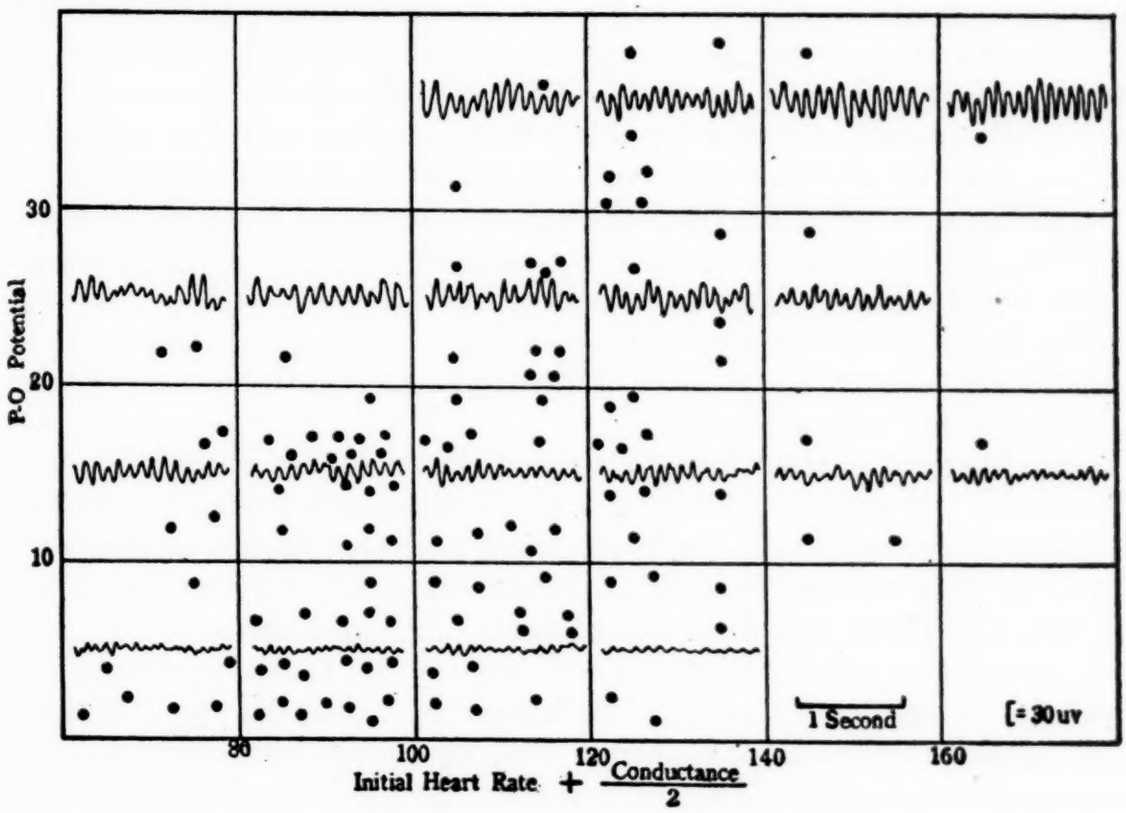

FIG. 1. Distribution of parietal-occipital EEG potentials and *initial heart rate + conductance/2*. EEG tracings are from individuals representative of activity in the respective cells of the distribution. $N = 120$; $r = 0.48$.

Most important among previously recognized factors is carbon dioxide, a product of cerebral metabolism. CO_2 favors decrease of potential and increase of frequency of the EEG (**22, 30, 41, 42, 43, 44, 45**) and produces an associated vasodilatation in the brain (**14, 41, 70, 78**). Related influences during activity such as the effects of acidity and changes in levels of positive or negative D.C. potential of the brain are likewise recognized (**32, 34, 52, 53**), as of course are the concomitant utilization of glucose and oxygen. By contrast the possibility of appreciable and significant influence of autonomic activity on the EEG has not been generally conceded, notwithstand-

ing EEG—vasomotor correspondences (**20, 28**) and accumulating evidence for participation of acetylcholine in nerve transmission in the brain. If it be granted, however, that during activity intrinsic chemical influences and differences in metabolite (especially CO_2) production are most important in determining EEG and cerebral vasomotor tone, it must follow that measurements of these values, were they available, would give relatively higher correlations with EEG than our autonomic measurements. But our synergistic autonomic measure gave a correlation of $r = .48$. A properly weighted combination of this index of autonomic influence with an independent measure of chemical influences should, then, give still higher correlations approaching $r = 1.00$ and offering high predictive value. In other words, if we may assume the respective chemical and autonomic relations with EEG to be completely independent variables, all important factors at this level of control would be accounted for, and if we concede the great importance and presumably high correlations to be offered by the still unmeasured intrinsic chemical factors, the correlations with autonomic function we have presented could hardly be any larger than they are.

In the light of these considerations the importance of the correlations here shown is evident. Possible implications for cerebral function may be considered.

(1) Positive correlations between palmar galvanic activity (conductance) and alpha amplitude in the resting state indicate a positive relation between sympathetic function and the source of the alpha rhythm. By the nature of mechanisms previously outlined this implies a positive relationship between EEG and the activity of the thalamus, the hypothalamus, and the sympathetic system. Hypothalamic influences such as indicated by Kennard (**55**), Obrador (**72**), and Murphy and Gellhorn (**66, 67**) may be involved. And since excitation, attention, and related activity involving the cortical level produces 'blocking' of alpha and results in a negative relation between EEG potential and concomitant galvanic reactions, these positive correlations with galvanic level in the resting waking state must indicate a subcortical preponderance over the effects of cortical function, if not a degree of actual subcortical domination of the cortex.

A subcortical inhibition, limitation, or regulation of cortical activity may conceivably be the natural result when cells in the outer meshwork of the cortex are made to beat synchronously at ten per second, much slower than their intrinsic rate. The relatively high positive potential swings of the alpha rhythm must, furthermore, render those cells half of the time relatively refractory to stimulation and correspondingly interrupt ongoing activity. The alpha rhythm may thus be not merely a symptom but a contributing factor in

mental relaxation. Furthermore, indications that the alpha potential recorded from the outside of the skull is affected in opposite directions by activity at higher and lower levels of the nervous system, may account for the occasional absence of relation between recorded EEG and obvious changes in cerebral activity. Excitation which increases activity at both higher and lower levels in a balanced manner may not affect the alpha potential. A similar problem in a balanced system has long beset studies of autonomic function (**19**). One has to catch such a system off balance to show an effect.

(2) Sympathetic activity, by its vasoconstrictor action on the cerebral blood vessels (**13, 35, 38, 71, 75, 83**) and its limitation of blood flow may also serve to limit or regulate cerebral function thereby preventing excessive or self perpetuating effects of excitation. Murphy and Gellhorn (**66, 67**) have recently demonstrated greatly increased brain potentials from cortical stimulation when sympathetic influences were eliminated by cutting sympathetic nerves. It is of further interest in this connection that Bronk and Pitts and their associates (**10, 11, 73, 74**) found 10 per sec. activity more or less characteristic of hypothalamic and sympathetic mechanisms. If this 10 per sec. autonomic rhythm is supplied along with the sympathetic impulses to the cerebral blood vessels, it unquestionably could contribute to the alpha rhythm. This would provide an important additional mechanism contributing to the association of alpha potential with cerebral vasoconstrictor tone (**20–28**).

Parasympathetic vasodilator nerves to the brain are by contrast apparently characterized by low potential fast activity (**20, 21, 22**). Thus, like vasodilator carbon dioxide, and like increase of frequency during excitation of the cortex, they may not only increase low potential fast activity, but correspondingly decrease 10± per sec. pacing of the cortex. Inhibition of parasympathetic activity, on the other hand, may not only lead to increase of heart rate, reduction of acetylcholine in the brain, but also to increased alpha activity with associated cerebral vasoconstriction, and limitation of cerebral function.

Accordingly, in the present study of the resting waking state our results suggest that the presence of a low level of central excitation permits dominance of the cortex by nerve potentials from the waking thalamic, hypothalamic, and autonomic centers, and that we consequently obtain positive correlations between EEG potentials and peripheral autonomic function. This is the opposite of the relationships obtained under conditions of central excitation where activity and increased metabolism in the outer cortical meshwork predominate over subcortically determined rhythms. There are, however, two stimulating conditions in which subcortical and autonomic

regulatory effects possibly may predominate. In conditions of 'anticipation' involving increased 'readiness to respond' to familiar stimuli, an elevated cortical 'tension' before the stimulus, and a subcortical and autonomic mobilization after the stimulus may give rise, not to a 'blocking,' but to a 'facilitation' of alpha potential (**28, 86, 87**). Also, in conditions of strong emotional arousal, conceivably involving a 'relative functional decortication' (**15**) type of response, suppression of central activity and reinforcement of peripheral autonomic effects may possibly increase or "facilitate" EEG potentials of alpha and slower frequencies (**46, 50, 51, 58, 81, 85**). Evidence that cortical and subcortical influences on the EEG mutually oppose one another accounts for many unexplained electroencephalographic phenomena and offers a means for the investigation of important cortical-subcortical relationships.

Summary and Conclusions

In a study of 120 persons in the resting waking state a correlation of $r = .28 \pm .06$ between parietal-occipital EEG potential and palmar skin conductance and a correlation of $.33 \pm .06$ with heart rate were demonstrated. Combination of skin conductance with heart rate gave a correlation of $.48 \pm .05$, thereby suggesting synergistic autonomic action on the EEG. That these correlations obtained in the resting waking state are of opposite sign to those typical of excitatory effects after stimulation, suggests that the low level of cortical activity and metabolite production in the resting state permits dominance of the cortex by the subcortically determined $10 \pm$ per sec. rhythm and by vasoconstrictor regulatory effects from the autonomic system. It is pointed out that in certain conditions of anticipation where cortical activity precedes the stimulus and in certain emotional reactions where there may be a suppression of central ideational activity and an exaggeration of subcortical and autonomic effects, such a relationship may explain instances of 'facilitation' of alpha and slower EEG potentials. It is suggested that levels of autonomic activity giving correlations with EEG in the resting state opposite in sign to correlations produced in conditions of cortical excitation provide evidence of opposing cortical vs. subcortical influences on cerebral function and offer a means for studying phenomena of mutual cortical-subcortical regulation.

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A METHOD FOR THE MAINTENANCE OF CHRONIC SPINAL ANIMALS

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The physiological psychologist and the physiologist are frequently confronted with the problem of maintaining seriously mutilated experimental animals for long periods of time. In the case of decerebrate preparations the need for controlling the body temperature is essential and may require that the animal remain immersed in a thermostatically controlled bath (**1**). In the case of the spinal animal—if the transection is high in the cord—artificial respiration becomes necessary (**2**). Even when the transection is farther down, the debility produced is so extensive that the subject may demand almost continuous care and attention. It is no doubt because of practical difficulties of this sort, that observations of decorticate, decerebrate, and spinal preparations have, as a matter of necessity, been confined in numerous instances to acute rather than to chronic specimens. The object of the present report is to describe briefly a method by means of which large spinal mammals, like dogs or cats, can be kept in a healthy and active state with a minimum of effort, when completely transected in the thoracic or in the lumbar region.

Problems of Maintaining the Chronic Preparation

In early attempts to maintain spinal dogs in cages with wooden shelves and concrete floors, it was found in our laboratory that pressure sores or 'shelf sores' were unavoidable even thought he animal might possess a heavy coat of hair. It was also found that irritation from fecal matter and from urine was almost continuous and could not be ameliorated by the use of salves or ointments. The animal could be kept clean by frequent washing, but if this was done, it never had a chance to become completely dry. The water and the lack of proper air circulation on parts of the body which were pressed together—as for example, the medial surface of the leg against the abdomen—soon combined to produce an aggravated skin rash which got progressively worse. In addition to these difficulties there was likely to develop a swelling or edema of one or both of the paralyzed legs. And, since whatever reclining posture the animal assumed would obviously cut off the blood circulation from parts of its insensi-

tive hindquarters, its position had to be constantly changed by someone acting literally in the capacity of nurse. If this was not done, a gangrenous condition would eventually set in.

The most natural solution to these problems would appear to be to use very few experimental subjects (perhaps only one) and to keep them under continual observation. Such a method is, of course, utterly impractical in most laboratories.

Could not these difficulties be overcome if the preparation was supported in a standing position by properly designed slings or hammocks? In this posture it would not soil itself with excretion, and frequent washing would be unnecessary. Whenever it was washed, moreover, it would dry readily, since no parts of the body would remain in physical contact with other parts, and air could circulate freely over all the body surfaces. To test out this possibility a broad canvas hammock was placed under the chest of one of our spinal dogs behind the legs. The hammock was held in place by a loose harness or collar around the neck. Soft sponge-rubber slings were then arranged so as to support each of the hind legs at their point of junction with the body. But the slings were found to cut off circulation in the femoral and saphenous vessels, and this method had to be abandoned.

We then tried supporting the posterior end of other preparations by the tail, but with this method other difficulties were encountered. In order to fasten a hook or loop to the tail which would have sufficient tensile strength to support the weight of the body, it was necessary to tape or otherwise bind the tail so tightly that circulation was also hampered. In the course of a few days the flesh upon the tail began to rot, and the method had to be given up.

Present Procedure

The technique which was finally adopted is illustrated in Figs. 1 and 2. Fig. 1 shows the method of piercing the tail with a metal pin. This operation is performed either at the time of the transection when the animal is under surgical anesthesia, or after the transection when no anesthetic is necessary because of the loss of sensitivity in the caudal parts. The piercing of one of the tail vertebrae is accomplished with a small mechanic's drill which is rotated at high speed in the hand-piece of an electric dental motor. The entire procedure of drilling the tail, and inserting and fastening the pin, can be completed in two minutes or less.

When supported by the tail in this manner the paralyzed portion of the preparation will hang free and clear. Circulation in the tail, as well as in other parts is unaffected. Should the tail show a tendency to pull apart, as it may if the initial drilling is too close to the

end, or if the subject should prove to be unusually active, it is a matter of but a few moments to move the pin to a larger vertebra closer to the body of the preparation.

A diagram of the complete arrangement is shown in Fig. 2. The hammock which passes under the chest is hung from a substantial metal framework, which can be adjusted by pulleys to the height of any particular specimen. The hind feet are held on a level with the

FIG 1. Showing method of piercing the tail with a metal pin by means of which the posterior half of the preparation can be supported.

floor by an adjustable strap to the tail pin. Urine and feces are carried off by the drain behind the animal. A head board, made of plywood sheathed with galvanized sheet iron, clamps to the metal framework which holds the hammock. This head board, shown in cross section in Fig. 1, is cut out in the middle and fits over either side of the back of the dog. Without a muzzle or other physical restraint,

the subject is thus prevented from chewing at the hammock or from opening the wound on its back before this has completely healed.

Unless the transection is high in the cervical region—which has not been the case with our preparations—the front feet are in no way paralyzed. The animal can therefore either stand upon the floor or it can hang in the hammock. In the latter instance, the front feet may be placed on the foot shelves arranged at a convenient height

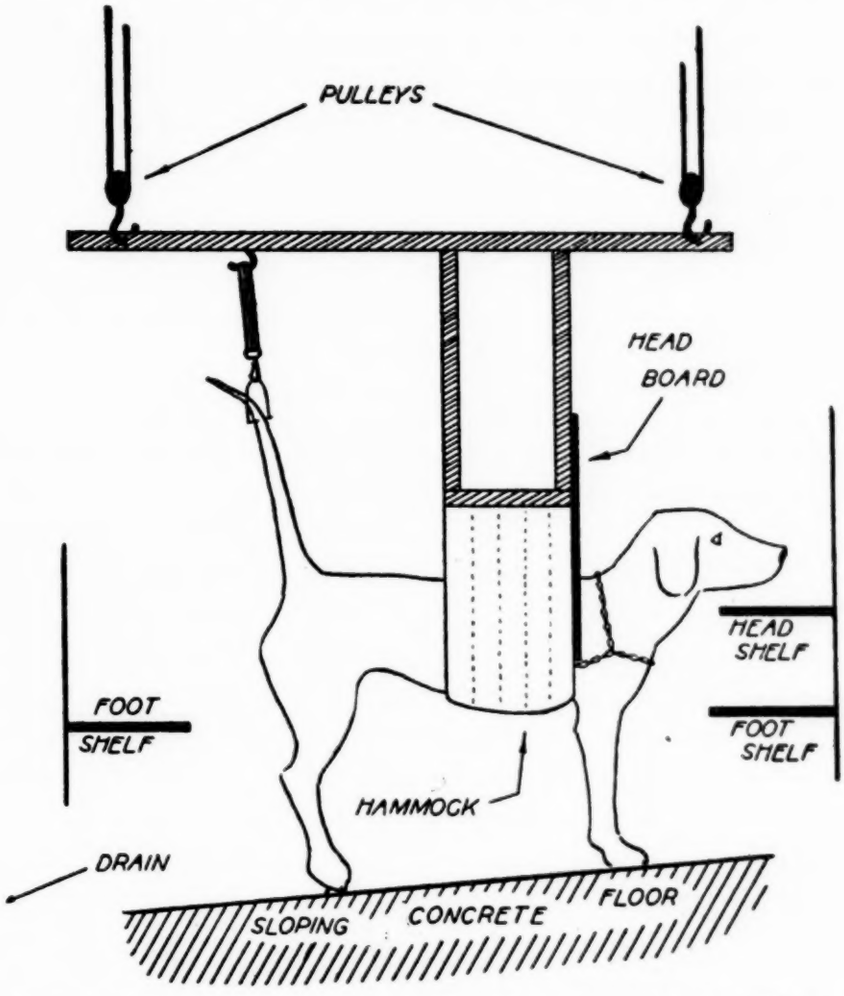

FIG. 2. Diagram of complete apparatus. The hindquarters of the subject hang free and clear and are not likely to be soiled by excretion. Circulation is unaffected and there is no opportunity for pressure sores to develop in the paralyzed parts of the body. Foot and head shelves permit the animal to lie in the hammock and rest or sleep. The hind feet are periodically raised and lowered from the rear-foot shelf, so as to prevent their swelling from continually hanging downward.

before it (*cf.* Fig. 2). At the same time the head can be rested on the head shelf. This gives that portion of the organism anterior to the the transection a posture similar to lying down. The spinal dog will frequently sleep in this position.

The only special attention required by the preparation in such an apparatus—above and beyond that demanded by the intact laboratory animal—is as follows:

1. The bladder must be mechanically emptied by palpation of the lower abdomen, at intervals of from 4 to 8 hours.

2. To avoid an edematous condition of the hind feet which may arise from their continually hanging downward, it is necessary at stated periods to place them on the rear-foot shelf behind the animal. An alternating schedule of raising and lowering the feet at 8 A.M., 12 noon, 6 P.M., and 10 P.M. has proven sufficient to maintain the hind quarters in good condition so far as swelling is concerned.

Animals with thoracic or lumbar transections, whose disposition is such that they can satisfactorily adjust to this somewhat confining situation, can be maintained in the manner indicated for indefinite periods. They need only be removed for experimentation or for other observations.

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THE BENTONITE ELECTRODE

BY LT. LAWRENCE LeSHAN AND SGT. AARON FARBER

In his article, 'Electroencephalography' (1), Gibbs states that the electrode recommended by Turner and Roberts (2), is unsatisfactory compared to the collodion electrode. However, working at an Army General Hospital, we have carefully tested the bentonite electrode and worked out a technique of application that, in our estimation, gives it significant advantages over other methods now in use.

Testing was first done by applying bentonite electrodes as closely as possible to collodion electrodes and comparing results. This test was made with a series of 20 patients with no differences appearing in the encephalogram, although the resistances were usually lower in the bentonite electrodes.

It was found possible to obtain resistances as low as 500 ohms with this method and an average resistance of about 2000 ohms has been maintained in over 250 records.

Since a large proportion of the cases at this hospital are head wounds, the great advantages of the bentonite electrode may be easily seen. There is no necessity for pressure on the scalp during application and an electrode may be placed directly in the defect of a freshly healed and still tender wound.

The technique used is as follows: (1) The area is cleaned with acetone. This is done with a cotton swab. (2) Cambridge Electrode Jelly is rubbed lightly into the scalp with a finger. This serves the dual purpose of providing a contact for the bentonite and stiffening the hair and holding it away from the electrode. (3) A small amount of bentonite paste, the size of a large pea, is placed on the jelly with an applicator stick. The bentonite paste is a thick viscous mixture of bentonite, 200 mesh, and a saturated solution of calcium chloride. A special electrode is placed in the paste. The electrode consists of a solder disc about 5 mm. × 0.5 mm. attached to about 14 inches of 32 gauge copper wire. A phone-tip jack is placed on the other end of the wire. Electrodes are regarded with suspicion when resistance is over 10,000 ohms. Electrodes on the ear (ground) may also be applied in this manner. However, it is preferable to use either the standard collodion electrode or an ear-ring variant, as grounds.

Using standard army placements (3) with this technique, a set of eight electrodes and two ground electrodes can be applied in 5–10 min.

In the experience of both authors, this electrode is superior in all head wound cases particularly and in all cases, generally, except where the patient is uncooperative. Since these electrodes do tend to tear loose easily, in these cases, the standard collodion electrode is recommended.

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